Long Range Analysis of the Need for Cleanup and Closure of the Old Radioactive Waste Burial Ground

- Human Health Risk Analysis -

July 16, 2001

Prepared for the

Savannah River Site Citizens Advisory Board

Prepared by the

Old Radioactive Waste Burial Ground Focus Group

The following members of the Old Radioactive Waste Burial Ground Focus Group prepared this report and agree with the conclusions presented herein.

Signature Page

Jimmy Mackey ____________________ Date: 7/16/01
Administrative Lead

Lee Poe ____________________ Date: 7/16/01
Technical Lead

Todd Crawford ____________________ Date: 7/16/01

Gerald Devitt ____________________ Date: 7/16/01

Bill Lawless ____________________ Date: 7/16/01

Bill McDonell ____________________ Date: 7/16/01

Karen Patterson ____________________ Date: 7/16/01

Gene Rollins ____________________ Date: 7/16/01

Wade Waters ____________________ Date: 7/16/01

William Willoughby ____________________ Date: 7/16/01

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Acronyms, Abbreviations, and Use of Scientific Notations

ANL	– Argonne National Laboratory
BEIR	– Biological Effects of Ionizing Radiation
BNFL	– British Nuclear Fuels, Ltd.
BNL	– Brookhaven National Laboratory
Bq	– Becquerel (1 Curie = 3.7×10^{10} Becquerel)
BSRI	– Bechtel Savannah River Company
C	– Carbon
CAB	– Citizens Advisory Board
CEDE	– Committed Effective Dose Equivalent
CERCLA	– Comprehensive Environmental Response, Compensation, and Liability Act
Cd	– Cadmium
CFR	– Code of Federal Regulations
Ci	– Curies
CIF	– Consolidated Incineration Facility
CMS/FS	– Corrective Measures Study/Feasibility Study
Co	– Cobalt
COI	– Constituents of Interest
Conc.	– Concentration
Cs	– Cesium
DDREF	– Dose and Dose Rate Effective Factor
DoD	– U. S. Department of Defense
DOE	– U. S. Department of Energy
EDE	– Effective Dose Equivalent
EM	– Environmental Management
EPA	– U. S. Environmental Protection Agency
ER	– Environmental Restoration
ERDA	– Education, Research and Development Association
FG	– Focus Group
FRC	– Federal Radiation Council
FY	– Fiscal Year
Hg	– Mercury
HS	– Hot Spots
HW	– Hazardous Waste
I	– Iodine
IC	– Institutional Control
ICRP	– International Commission on Radiological Protection
IM	– Information Management
INEEL	– Idaho National Engineering and Environmental Laboratory
ISPR	– Independent Scientific Peer Review
L	– Liter (approximately the same as a quart)
Lab.	– Laboratory
LANL	– Los Alamos National Laboratory

LBNL – Lawrence Berkeley National Laboratory
LLE – Loss of Life Expectancy
LLNL – Lawrence Livermore National Laboratory
LLRWDF – Low Level Radioactive Waste Disposal Facility
LLW – Low Level Waste
LNT – Linear No Threshold
LUC – Land Use Control
LUCAP – Land Use Control Assurance Plan
m^3 – Cubic Meter
MCL – Maximum Concentration Level
MEI – Maximally Exposed Individual
MLLW – Mixed Low Level Waste
mm – Millimeter
MNA – monitored natural attenuation
mrem – Millirem (1/1000 rem)
MWMF – Mixed Waste Management Facility
N/A – Not Applicable
NAS – National Academy of Science
Nat. – National
NBS – National Bureau of Standards
NCRP – National Council on Radiation Protection and Measurement
Np – Neptunium
NRC – U. S. Nuclear Regulatory Commission
NTS – Nevada Test Site
NUREG - Nuclear Regulatory Commission Technical Report Series
ORNL – Oak Ridge National Laboratory
ORWBG – Old Radioactive Waste Burial Ground
OST – Old Solvent Tanks
OU – Operational Unit
PAs – Performance Assessments
Pb – Lead
PCE – Tetrachloroethylene
pCi/L – picoCuries / Liter
PEIS – Programmatic Environmental Impact Statement
PP – Proposed Plan
Pu – Plutonium
RCRA – Resource Conservation and Recovery Act
Ref. – Reference
Rev. – Revision
RFETS – Rocky Flats Environmental Technology Site
ROD – Record of Decision
SAIC – Science Applications International Corporation
SCDHEC – South Carolina Department of Health and Environmental Control
SEIS – Supplemental Environmental Impact Statement
Sr – Strontium
SREL – Savannah River Ecology Laboratory

SROO – Savannah River Operations Office
SRS – Savannah River Site
Sv – Sievert (1 rem = 0.01 Sievert)
SW – Southwest
T – Tritium
Tc – Technetium
TCE – Trichloroethylene
TLD – Thermoluminescent Dosimeters
TRU – Transuranic
U – Uranium
US – United States
VOC – Volatile Organic Compounds
Vol. – Volume
WIPP – Waste Isolation Pilot Plant
WMER – Waste Management and Environmental Remediation
WSRC – Westinghouse Savannah River Company
yr. – Year
4MB – Fourmile Branch
μg/L – Micrograms per Liter
ηCi/g – NanoCuries per Gram

Use of Scientific Notation

Very small and very large numbers are sometimes written using "scientific notation" or "E-notation" rather than as decimals or fractions. Both types of notation use exponents to indicate the power of 10 as a multiplier (i.e., 10^n, or the number 10 multiplied by itself "n" times; 10^{-n}, or the reciprocal of the number 10 multiplied by itself "n" times).

For example: $10^3 = 10 \times 10 \times 10 = 1{,}000$

$$10^{-3} = \frac{1}{10 \times 10 \times 10} = 0.001$$

In scientific notation, large numbers are written as a decimal between 1 and 10 multiplied by the appropriate power of 10:

4,900 is written $4.9 \times 10^3 = 4.9 \times 10 \times 10 \times 10 = 4.9 \times 1{,}000 = 4{,}900$
0.049 is written 4.9×10^{-2}
1,490,000 or 1.49 million is written 1.49×10^6

A positive exponent indicates a number larger than or equal to one; a negative exponent indicates a number greater than zero but less than one.

In some cases, a slightly different notation ("E-notation") is used where "x 10" is replaced by "E" and the exponent is not superscripted. Using the above examples

$4{,}900 = 4.9 \times 10^3 = 4.9E+03$
$0.049 = 4.9 \times 10^{-2} = 4.9E-02$

$1,490,000 = 1.49 \times 10^6 = 1.49E+06$

Executive Summary

The Old Radioactive Waste Burial Ground (ORWBG) Focus Group (FG) was formed in 1998 by the Waste Management and Environmental Remediation Committee of the SRS Citizens Advisory Board (CAB). The FG members were citizens interested in evaluating current and future health risks posed by the ORWBG and its contaminants. The purpose of the FG was to determine the level of risk posed by the ORWBG, and the amount and type of remediation necessary to protect the public from radionuclides, and to present those findings to the SRS CAB for consideration and recommendations.

The FG used the Corrective Measures Study/Feasibility Study (CMS/FS) prepared by Bechtel Savannah River Inc. as the basis for their evaluation. However, the FG considered the point-to-point straight line model used in the CMS/FS to determine concentrations of contaminants migrating from the burial ground to the nearest surface water (Fourmile Branch) to be too conservative. They requested an Independent Scientific Peer Review to reevaluate the concentrations of contaminants migrating from the burial ground using a less conservative model, but one the FG considered more true to the actual hydrogeologic conditions. This model assumed that the movement of the contamination was planar and not a single straight line and that the contamination entered the creek along this plane and not at a single point. Therefore, it is an averaging model. In addition the FG evaluated the likelihood of active and passive institutional controls limiting the public's access to the area near the ORWBG, based on recent DOE statements concerning long-term stewardship and the maintenance for perpetuity of contaminated sites like the ORWBG. Although the FG does not believe that restricted access can be maintained in perpetuity, they assumed the ORWBG would not be accessible to the public for a longer period of time than the CMS/FS took credit for. Finally the FG examined the effectiveness of capping the burial ground, and vegetating the cap for the specific purposes of controlling erosion and limiting the ability of deep-rooted plants, burrowing animals and insects to penetrate the clay cap.

Doses were estimated for the assumptions that (1) an individual derived all his drinking water from (one of) four Fourmile Branch/Savannah River locations downstream of the ORWBG (from Road A on SRS to the Port Wentworth water intake), (2) an individual lived on the burial ground, and (3) an individual (termed the intruder analysis) built a house with a basement in the buried waste, and grew his food in contaminated soil. For the latter two assumptions, a one-year exposure was used because the FG assumed that throughout the 10,000-year analysis period, passive institutional controls would be in effect, and although a person might trespass on the ORWBG site, authorities would discover the intrusion and remove the intruder.

Current regulatory standards for drinking water are 4 mrem per year from all man-made beta- and gamma-emitting radionuclides combined. If a hypothetical person were to violate active institutional controls and get all his drinking water from Fourmile Branch at Road A on the SRS, he could incur a dose of about 3.5 mrem per year due to the tritium concentration currently in Fourmile Branch from the ORWBG. The dose from contaminants from the ORWBG never exceeds the drinking water standard at Road A. Drinking water further downstream from the ORWBG have doses well below the regulatory standard. The nearest source of public drinking water is Port Wentworth, GA., about 110 river miles from the mouth of Fourmile Branch. Table ES-1 presents estimates of the lifetime risks of a latent cancer fatality from these doses.

If institutional controls and erosion controls failed, an individual could be exposed to waste about 1,750 years from now. If that person resided on top of the waste, but didn't grow his food in it, he could receive a 50-year committed annual dose of approximately 810 mrem (annual dose of 16 mrem). Proper passive IC would preclude these activities. Table ES-1 presents the risk of a latent cancer fatality from this dose.

An intruder to the ORWBG site 3,000 years from the present could get a maximum 50-year committed dose of 14,000 mrem (annual dose of 280 mrem) from a single year exposure if erosion controls and institutional controls failed. The maximum 50-year dose commitment could be higher, estimated to be 16,000 mrem, if the intrusion occurred at 1750 years. Again, proper passive IC would prohibit this activity. Table ES-1 presents the risk of a latent cancer fatality from these dose.

Table ES-1.
The potential maximum annual doses for the various scenarios evaluated in this report and the lifetime risk of contracting a latent fatal cancer from those doses.

Exposure scenario	**Annual Dose (mrem/year)**	**Lifetime Risk of fatal cancer**
Groundwater/Surface water contamination		
At Road A * MEI (year 2000)	3.5	1.2×10^{-4}
MEI (year 2800)	0.77	2.7×10^{-5}
At Port Wentworth MEI (year 2000)	0.009	3.1×10^{-7}
MEI (year 2800)	0.002	7.0×10^{-8}
Surface Occupation		
Resident MEI (w/o erosion control or IC)	16	2.8×10^{-4}
Intruder MEI (w/o erosion control or IC)	280	3.5×10^{-3}

(Additional detail can be found in Appendix H, Table H-1)
* Location shows on Figure 5-2; page 5-5.

The SRS has many facilities and materials that represent much larger risks to the public and the environment than the ORWBG and its contaminants. The national budget is limited and finite. Resources must be spent wisely to ensure that they are first used to remediate situations that represent the greatest risks. (Vitrification of High-Level Waste is one such example.)

Given the uncertainties and conservatism in the dose and risk estimates presented in Table ES-1, the FG believes the potential for adverse health or environmental impacts from the ORWBG are extremely unlikely. These numbers were calculated to provide stakeholders and decision-makers with estimates to make informed decisions. They should not be interpreted as an indication of actual adverse impacts. The FG believes that the actual risks represented by these estimates are inconsequential, and may in fact, be zero.

Therefore, to conserve finite remediation resources by targeting cleanup activities toward those sites that pose the greatest risk to human health and the environment, the FG concludes that no further remediation is necessary to protect the public from tritium in the groundwater seeping into Fourmile Branch. The doses and risks could be unacceptably high if institutional controls failed and the cap eroded completely away, exposing the waste, several thousand years into the future. Therefore, the FG recommends (1) that DOE maintain stewardship of the ORWBG, including the placement of passive institutional controls, and (2) that the burial ground be capped with shallow rooted vegetation (for example, bamboo) to prevent erosion.

1.0 Introduction

1.1 Formation

At the November 11, 1998 meeting of the Environmental Restoration and Waste Management Subcommittee of the SRS CAB, the need for a Focus Group (FG) to follow plans for the remediation of the ORWBG was discussed and a recommendation was developed to establish a FG. The CAB formed the FG on November 17, 1998. The CAB requested that SRS and the regulators provide technical support for the group. The FG met on December 8, 1998 to develop a scope of work. The FG decided to review both the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) proposed actions and develop recommendations on the need for further cleanup of the ORWBG.

1.2 Goals and Objectives

The FG goals for the cleanup of the ORWBG:

- Cleanup/remediation should be performed only if the human health consequence and risk posed by the ORWBG are significant.
- Remedial actions should provide significant improvement in human health and be cost effective.

The FG objectives were to:

- Determine if the ORWBG conditions currently cause human health risks.
- Identify risk mitigations if risk levels cause significant human health risks now or could in the future.

1.3 Radiation Human Health Effects and Standards

Due to the importance of radiation and health in interpreting the significance of this report a short discussion is given.

Background Radiation and Perspectives

The average dose from background radiation to which all Americans are exposed is about 360 millirem per year (mrem/yr) from cosmic radiation, terrestrial radiation from the soil, and radon. Dose can vary by a factor of 2 across the United States and is much higher in some parts of the world. The modern life style adds small amounts of radiation exposure annually (flying across country in jet aircraft - 0.5 mrem/hour; chest x-ray – 10 mrem using modern equipment; average dose to people living in the United States from manmade sources – 64 mrem/yr; living in brick or stone homes adds an additional 200 mrem/yr.; etc.).

Technical debate continues on the health effects of exposures below 10,000 mrem as no adverse health effects below this dose have ever been observed and there is a developing body of literature indicating that some additional exposures over background may in fact be beneficial. (See Appendix H, Section H.7.3)

Risk is determined by multiplying the probability of being exposed times the exposure rate times the probability of a health effect from that exposure. (See Appendix H, Section H.5) If a person is not exposed, then the risk of a health effect is zero. All other exposure results in a calculable, though usually very small, risk.

Regulatory Standards

Standards are set based on concentrations of pollutants in environmental media and on radiation dose. In principle, regulatory standards are based on health effects if the standard is exceeded. Clearly, the public believes that standards are based on health effects and that if a standard is exceeded there will be a health consequence. But, this is not always true. Some standards are set based on health effects, but in practice many are set on what is achievable. Sometimes “achievable” is based on concentrations of a pollutant in the natural environment, sometimes “achievable” is based upon what the polluter can do technically to control emissions of a pollutant, sometimes “achievable” is based on economics, and sometimes “achievable” is based on the collective judgment of the standard setters when there are no data. In addition, in setting radiation standards, a linear non-threshold assumption has been used (extrapolating effects at high exposures to zero exposure). That is, doubling the exposure should double the adverse consequence of the exposure and no exposure is without consequence.

Consistency in Standards

As a result of the various methods of setting standards, there is much inconsistency among them. This inconsistency causes confusion because the public interpretation is that once a standard is exceeded there is a health effect. The DOE and the Nuclear Regulatory Commission (NRC) have established an exposure limit of 5,000 mrem/yr for workers but DOE has established an administrative limit of 2,000 mrem/yr. DOE, NRC, and the Environmental Protection Agency (EPA) have established an off-site public dose limit of 100 mrem/yr (all pathways). However, DOE and EPA have established an airborne pathway dose limit of 10 mrem/yr and a drinking water dose limit of 4 mrem/yr.

There is no conclusive scientific basis for any of the above standards. For instance, when setting the Maximum Contaminant Level (MCL) for beta particle and photon radioactivity for drinking water in 1976, EPA stated that “the limit was chosen primarily on the basis of avoiding undesirable future contamination of public water supplies as a result of controllable human activities” *(Radionuclides Notice of Data Availability Technical Support Document*, USEPA Office of Ground Water and Drinking Water, in collaboration with USEPA Office of Indoor Air and Radiation, and United States Geological Survey, March 2000). (Public water supplies are those serving at least 25 residents.) This limit was not based on health effects. In 1976 EPA estimated that continuous consumption of drinking water containing the dose established as the maximum permissible concentration would result in an exposure of 4 mrem/yr total body and a risk of 8 chances in 10 million of fatal cancer (using the linear non-threshold assumption) from a year’s exposure.

That 4 mrem/yr public drinking water standard has persisted over time and been extended to apply to individuals and to ground water. There is no scientific proof that exposures above 4 mrem/yr would cause a health effect.

Changing of Standards with Time

One cannot measure exposure rates from breathing air, consuming food, or drinking water. They have to be calculated using data on concentrations of radioactivity in air, food, and water, and scientific data on uptake and distribution of the radioactive elements in the human body. This science continues to improve. Thus, the relationship between concentrations in air, food, and water, and exposure continues to be clarified. For instance, the 1976 standard set a MCL for man-made beta- or gamma-emitting radionuclides at 4 mrem/yr to the total body. From that exposure rate, the MCL for tritium in drinking water was calculated to be 20,000 pico curies per liter (pCi/L). This is also the basis for the South Carolina drinking water standards. Using more recent data on exposure and dose but retaining the 4 mrem/yr drinking water standard, a new tritium MCL of 85,500 pCi/l (See Section 9) has been calculated. However, the EPA and South Carolina drinking water regulations have retained the more conservative 20,000 pCi/L concentration.

Comparison of Standards with Measurements and Calculations in this Report

Comparisons of environmental measurements and calculations with standards are included in this report on the ORWBG, but it should not be assumed that exceeding an existing standard would cause an adverse health effect. Many of the standards may change in the future, as science improves our understanding of the relationship between concentration, exposure, dose, and consequence.

The purpose of the ORWBG FG was to look at possible human health effects and not to focus on the regulatory issues associated with exceeding current regulatory standards.

1.4 Process

This report summarizes the two and a half-year review of activities to close the ORWBG. (Appendices A and B list FG members, and meetings held by the FG, respectively.) The FG held 28 meetings to review plans and status of SRS and the regulator's planning for ORWBG remediation and to provide an opportunity for the public to participate in the planned remediation. Early in the review process the FG concluded that their final report should show the risk to the public and workers from the ORWBG. Because the risk changes with time as the buried radioactive waste decays, it was concluded that the analysis should evaluate human health effects over a 10,000-year evaluation period. The waste had been buried between 1952 and 1974; significant time had elapsed since the last burial and therefore, many of the processes leading to release of contaminants were well underway.

The FG reviewed the analytical process used by SRS in the *Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-G* (WSRC-RP-98-4012) (called the "CMS/FS") and concluded it was excessively conservative because calculations were done only for the calculated maximum groundwater concentration at the ORWBG seep line into Fourmile Branch. The FG wanted to evaluate an analytical approach that estimated the average concentration because it is average concentrations that are relevant to health effects from drinking water. Thus, the FG developed a scope of work for developing a model, using the CMS/FS contaminant transport conditions, to estimate human health effects at several locations using average, rather than maximum, concentrations. At the July 25, 2000 meeting the CAB agreed to this scope of work and issued a request for proposal. The Education, Research and Development Association (ERDA) of the Georgia Universities was selected to perform the work. Participants in this ISPR work are nationally recognized experts led by Dr. Ratib Karem of the Georgia Institute of Technology. Work began in January 2000 and was completed in November 2000. The final ISPR report is Appendix C of this report. The approach developed in the ISPR report was used to calculate all stream concentrations in this report.

1.5 Report Content

This report is subdivided into the body and appendices. Appendices contain more details on the FG findings. This section (Section 1) presents the introduction of the FG study and a road map for the remainder of the report. Section 2 presents a summary of the FG deliberations, the conclusions reached in the study, and provides the FG recommendations. Section 3 provides a description of the ORWBG and defines the radionuclides and hazardous chemicals buried in there. Section 4 describes Institutional Controls (IC) planned for SRS. It also identifies some specifics on IC (active and passive) necessary for human health protection from radionuclides and hazardous chemicals buried in the ORWBG. Section 5 describes the rate of transport of the radionuclides and hazardous chemicals from the burial locations in the ORWBG through the water table to Fourmile Branch and then to the Savannah River. It also describes the human health consequences from these releases over a 10,000-year analysis period.

Section 6 presents the human health consequences and risk from occupying the ORWBG under both active and passive IC. Section 7 describes the health consequence and risk from intrusion into the wastes of the ORWBG or intrusion and use of the groundwater between the ORWBG to Fourmile Branch. Section 8 describes disposal at other DOE sites that may be comparable to the ORWBG disposals. It also defines the present accepted condition for these facilities, as a way to compare the consequence and risk posed by the ORWBG. Section 9 describes the applicability of the South Carolina Department of Health and Environmental Control (SCDHEC) drinking water standards to the ORWBG and how the FG feels they should be applied at SRS.

The report contains ten appendices. They are:

A. ORWBG Focus Group Membership

B. Meetings / Subjects of Focus Group Deliberations
C. Independent Scientific Peer Review (ISPR) Report
D. Groundwater Transport and Stream Concentrations
E. Human Exposures and Potential Dose from Radionuclides Released from ORWBG
F. Human Exposure and Potential Dose from Surface Occupation of the ORWBG Site
G. Human Exposure and Potential Dose from Intruder Occupation of the ORWBG and Land Between the ORWBG and Fourmile Branch
H. Human Health Effects from Exposure to Radiation and Radioactive Materials
I. Comparative Inventories for DOE Sites
J. History of Interactions Between Stakeholders, SRS, and Regulators on ORWBG Remediation.

2.0 Summary/Conclusions/Recommendations

2.1 Summary

The Focus Group examined the major pathways for contaminants from the ORWBG to reach humans:

1) Contaminants leaching from the ORWBG by precipitation infiltration moving to the water table and then moving with the groundwater to final release to Fourmile Branch and then to humans through drinking water.
2) Contaminants remaining in the ORWBG and being exposed to humans by several pathways including irradiation, consumption of crops grown in contaminated soils, breathing air-born contamination, and drinking near-by contaminated water.

The use of IC at SRS is a key part of the pathway of contaminants to humans so it was also examined.

Health Effects Are Unlikely to Individuals from ORWBG Contaminants Released to Water

The FG analysis shows that contaminants currently being released from the ORWBG to Fourmile Branch and those that may be released in the future are unlikely to cause health effects to individuals who drink Savannah River water. The tritium currently being released from the ORWBG is the most significant contaminant, and it results in a dose of only 0.009 mrem/yr to individuals using Savannah River water to supply their total drinking water. The dose from all radionuclides and all sources to the Savannah River is 0.07 mrem/yr. Both are insignificant compared to the standard of 4 mrem/yr. A dose of 0.009 mrem/yr for one year is calculated to result in about 3 chances out of 10,000,000 of a death due to cancer. The lifetime risk from drinking water at this contamination level is 30 chances of developing fatal cancer out of 1,000,000. Table 2-1 lists this data. Additional information can be found in Section 5 and/or Appendix H.

The above analysis considers the current and planned future exclusion of the public from SRS and the control of drinking water sources for SRS workers for 150 to 300 years into the future. It further assumes the 10-year average stream flow dilution of SRS streams and the Savannah River. Savannah River water is used for municipal drinking water for Savannah, Georgia, and Beaufort and Jasper Counties, South Carolina. The two drinking water plants supplying this are about 110 river miles downstream from SRS.

Table 2-1.
Maximum annual doses from drinking contaminated water from the ORWBG

Exposure scenario	Annual Dose (mrem/year)	Lifetime Risk of fatal cancer
At Road A MEI (year 2000)	3.5	1.2×10^{-4}
MEI (year 2800)	0.77	2.7×10^{-5}
At Port Wentworth MEI (year 2000)	0.009	3.1×10^{-7}
MEI (year 2800)	0.002	7.0×10^{-8}

(Additional detail can be found in Appendix H, Table H-1)

Institutional Controls Must be Maintained

Active IC is currently used by DOE to protect the public and workers from the hazards of materials buried in the ORWBG. Current SRS documents indicate that Active IC at SRS are planned for perpetuity. However, the ORWBG FG does not believe any government can guarantee perpetuity so the FG assumed that Active IC would exist for 150 to 300 years. During this period, the present SRS would be maintained under government control and the public would not be allowed onto the SRS.

At the conclusion of Active IC, the FG assumes SRS would transition to Passive IC. Passive IC requires different controls appropriate to the remaining hazards. Some portions of SRS would have essentially no restrictions on their use and others would have restrictions. It is desirable to specify some controls on the land now to mitigate problems that may occur otherwise during Passive IC. Controls are needed on the surface of the ORWBG to prevent significant erosion and consequent exposure of the waste. If surface erosion is not controlled, the present overburden could erode away and expose the waste in less than 2,000 years. However no restrictions are needed on the land south of Fourmile Branch (the ORWBG is just north of the Branch).

Health Effects Are Unlikely from Contaminants Left Buried in the ORWBG with Institutional Controls

With intact ICs, the ORWBG is unlikely to cause health effects to current or future generations from the buried waste in the ORWBG. Decay of the short-lived radionuclides would reduce the total radioactive waste to 1 percent of the original value in 100 years post-burial activity, and after 500 years to about 0.1 percent of the original activity. However, some long lived radionuclides, such as Plutonium-239, Carbon-14, and Technetium-99, would be essentially undiminished in 500 years. The FG analysis assumes, with a defense-in-depth perspective, that some Passive IC restrictions would be breached during the 10,000-year analysis period. Thus the health consequences of different breaching scenarios were calculated. Exposures from the different hypothetical scenarios were low and unlikely to cause health effects to the individual breaching the controls. Exposures would not be life threatening if they were for one year or less (the length of exposure calculated by the FG). Longer exposure times may also result in no adverse health effects but this analysis assumed that within one year of the breach, it would be discovered and corrected.

The most significant intruder scenario assumed that an individual constructed a homestead on the surface of the ORWBG with foundations and a basement over a location containing a maximum amount of buried plutonium. Contaminated soil was removed while digging the basement, spread over the garden surface, and the garden crops were consumed. The analysis showed that this intruder might receive a lifetime 50-year committed dose of 14,000 mrem. This dose commitment results from ingestion and inhalation of long-lived radionuclides such as plutonium. This 14,000 mrem 50-year committed dose is the equivalent of receiving 280 mrem/year for 50 years. This exposure could be calculated to result in an increase in the lifetime risk of developing a fatal cancer by 3.5 chances out of 1,000. This would represent an increase of about 1.5 percent over the natural lifetime incidence of fatal cancer in the U.S. population from all causes (see Appendix H).The passive IC will further significantly reduce this exposure but this was not included in the above values.

Intruding into and using the groundwater between the ORWBG and Fourmile Branch as the intruder's total drinking water supply for one year yields a calculated maximum 50-year committed dose of 55 mrem. This would occur about 600 years from now and be caused by neptunium-237 and carbon-14. Again, this dose would not be expected to result in adverse health effects.

Institutional Controls Eliminates Regulatory Issues

The State of South Carolina has regulatory authority over the "waters of the state" and has determined that remediation of the groundwater plume from the ORWBG is necessary. The present RCRA permit for the ORWBG requires SRS to meet the drinking water standard at the fence of the ORWBG and because the groundwater at that location exceeds the tritium MCL in drinking water, SRS has started a series of corrective actions. At the present time, the water with the highest tritium concentration is being collected and sprayed on nearby pine trees to allow natural processes to take up the tritium and transpire it to the atmosphere. This remediation was undertaken because the tritium concentration entering Fourmile Branch exceeded the drinking water standard of 20,000 pCi/L. Because no one drinks the water at this location and active controls limit all access, the FG considers it an inappropriate point to consider the need for remediation. If the present and future land use restrictions were considered and a mixing zone was applied, no remediation of the ORWBG would be necessary. This would lead to a more cost-effective remediation of the ORWBG.

2.2 Conclusions

The main conclusion of the ORWBG FG study is that the ORWBG poses no human health impacts now or into the future under the proposed ICs. Thus, there is no need for remedial action at the ORWBG to protect human health.

The ICs are part of the Long Term Stewardship Program and the Land Use Control Assurance Plan. At this time the specifics of these controls have yet to be institutionalized.

To further protect workers and the public (should Passive IC fail) the FG does recommend that DOE:

1. Stabilize the solvent tanks and cover them with low permeability clay soil cover to put that area in a condition similar to the remainder of the ORWBG.
2. Develop a land management concept that ensures minimal erosion and that keeps deep-rooted plants and burrowing animals off the surface of the ORWBG.

With these remedial actions in place the FG concludes that there is no human health threat to the workers or to the public from the ORWBG in the near-term or the long-term.

2.3 Recommendations

The FG has developed recommendations for consideration. They are drawn from the FG review of ORWBG information and the FG analysis in this report. The recommendations one through four are taken directly from the conclusions (Section 2.2) of this report which are needed to reach the conclusion that the ORWBG posed no human health threat in the near-term or the long-term. Recommendation five is made to ensure near-term and long-term calculated values for individual COIs appropriately reflect measured transport conditions. Periodically there is discussion of exhumation of some of the buried waste; thus recommendation six provides the FG consideration on this issue. The last recommendation provides a means of meeting the present environmental regulations even though no human health risk exists. Backup information can be found in this report in the sections indicated. The recommendations are:

1. Cease the current collection of tritium-containing groundwater and irrigation of the forest as soon as possible (Section 2 Conclusions and Appendix C)
2. Develop IC specific to the ORWBG and the area between the ORWBG and Fourmile Branch by April 2002. (Section 2 Conclusions, Section 4 and Appendix G)
3. Fill the solvent tanks with grout to stabilize them and then cover this portion of the ORWBG with 2 to 8 feet of low permeability soil to match the rest of the ORWBG. (Section 2 Conclusions and Section 3)
4. Develop a land management strategy to minimize erosion, prevent deep-rooted plants from encroaching, and discourage burrowing animals and insects from

bringing waste to the surface. (Section 2 Conclusions, Sections 6 and 7, and Appendixes F and G)

5. Consider refining the groundwater transport calculations for Volatile Organic Compounds (VOCs) and other Constituents of Interest (COIs) (other than tritium) in order to be consistent with measurements. (Appendixes C and D)
6. Do not excavate buried plutonium from the ORWBG. (Sections 4 and 7 and Appendix G and I)
7. Establish a mixing zone for the ORWBG groundwater plume during active and passive IC. Consider different mixing zones for active IC and for passive IC (Sections 5 and 9, and Appendix D)

3.0 Description of ORWBG

The Old Radioactive Waste Burial Ground (ORWBG) is an inactive landfill in E-Area near the center of SRS. It was used between 1952 and 1974 for disposal of solid low-level radioactive waste and hazardous wastes. Contaminated groundwater from the ORWBG flows towards and outcrops into a ditch that feeds Fourmile Branch. Most of the low-level waste was placed in earthen trenches 20 feet wide, 20 feet deep and up to 700 feet long. Generally, four feet of soil was placed on top of the waste. The ORWBG contains about 7,125,000 cubic feet of waste. Approximately 90 percent of this waste is job-control waste, such as paper, coveralls, protective clothing, and cardboard boxes. Irradiated metal scrap makes up about 7 percent and the remaining 3 percent includes a wide variety of natural and man-made radioactive materials, contaminated equipment, and absorbed solvents and oils.

In addition, 22 underground storage tanks remain in place near the center of the ORWBG and are considered part of it. They contained organic waste (including spent plutonium-uranium extraction [Purex] solvent from Separations Facilities and smaller amounts of tritiated pump oil). After aging, the solvents were removed from the tanks for incineration. Use of the solvent tanks ceased in 1977 and most of the remaining liquids were transferred to the New Burial Ground (617-7E). Small residual liquid and solids remain in some of the solvent tanks.

3.1 Constituents of Interest (COI)

Detailed studies (summarized in Ref. 3.1) have determined the inventory, location, and form of the wastes in the ORWBG. COIs, defined as waste that are mobile, hazardous, and with large inventories, and/or long radio-active half-lives, include:

- VOCs
  - Drummed scintillation solutions, waste oils in sorbent materials, residues from decontamination operations
- Hazardous metals
  - Cadmium (Cd) – scrap metals from reactor operations or fuel and target
  - Lead (Pb) – radiation shielding
  - Mercury (Hg) – tritium pumps, dissolution catalyst
- Radioactive Nuclides
  - Tritium (T) – spent melts, process equipment
  - Carbon (C)-14 – reactor moderator decontamination
  - Cobalt (Co)-60 – reactor components
  - Strontium (Sr)-90 – separations waste
  - Technetium (Tc)-99 – separations waste
  - Cesium (Cs)-137 – separations waste
  - Uranium (U)-235, 238 – fuel fabrication and separations waste
  - Neptunium (Np)-237 – separations waste
  - Plutonium (Pu)-238, 239 - separations waste

About 5.1 million curies were buried. Most was contributed by T (58%) and Co-60 (37%). Decay of the short-lived radionuclides after 100 years would reduce the total radioactive waste to 1 percent of the original activity, and after 500 years to about 0.1 percent of the original activity (about 51,000 curies after 100 years, and 5,100 curies after 500 years). The residual 500-year radioactivity would be associated primarily with C-14 (3,600 Ci), Pu-238 (390 Ci), and Pu-239 (1,500 Ci).

3.2 Hot Spots

Survey of the locations of the buried waste indicated the potential for localized concentrations (termed "hot spots") of the radioactive and hazardous constituents after 100 years. Leaching would deplete the inventories of T and some of the uncontainerized C-14, leaving the remainder of the uncontainerized C-14, the C-14 deionizer beds contained in stainless steel and overpacked in concrete casks. Transuranic isotopes (Np-237, Pu-238, & Pu-239) would also remain, primarily in concrete culverts in the radioactive hot spots. Also there is an area in the ORWBG that has most of the disposal of mercury that will also persist long into the future. The remaining COI's would be distributed uniformly within the burial ground area. The hot spots areas are defined in the CMS/FS (Ref. 3.1).

Corrective action for remediation of the ORWBG proposed by DOE includes institutional control for 100 years (or more) (Ref. 3.2). As subsequently detailed, the FG considers this a baseline condition for evaluation of the need for additional corrective measures.

3.3 Corrective Measures

In February 1998, interim corrective measures for the ORWBG were completed in accordance with the CERCLA. A low-permeability native soil cover was installed to reduce contaminant migration to the groundwater, potential soil erosion, worker risk, and spread of contamination, and to stabilize the surface of the ORWBG. This cover is from two to eight feet deep and is sloped to promote stormwater runoff. It was completed at a cost of about $8 million. The solvent tanks were not covered during the 1998 interim action. The interim action for the solvent tank area was delayed and is included in the CMS/FS for the ORWBG (Ref. 3.1).

The ORWBG remediation process, described in this section, has had continual input from the stakeholders, including the CAB, because it has the potential to be one of the largest remedial actions undertaken at SRS. Appendix J summarizes these inputs and the Focus Group's judgments on the impacts of this interaction on past remediation.

Remote video surveys of the insides of the solvent tanks revealed no evidence of tank breaching. It is not known if any of the solvent tanks leaked and contaminated the underlying soils. As stated in Ref. 3.1, soil sampling under the tanks would incur implementability restrictions, health and safety concerns, and excessive costs. DOE, SCDHEC, and EPA agreed in August 1998 that a low permeability cap should be placed over the solvent tanks to manage the uncertainty of possible leaks.

The ORWBG Focus Group recommends that the solvent tanks be filled with grout to stabilize them in addition to covering this portion of the ORWBG with from 2 to 8 feet of low-permeability native soil. This places the same soil cover over the entire ORWBG. The CMS/FS estimated this remediation would cost about $3.3 million dollars. The CMS/FS analysis indicates that this alternative meets all necessary remediation requirements. Installation of this cap would mitigate infiltration of rainfall and would be much less expensive than sampling the soil under the tanks to determine if leakage has occurred. Grouting the tanks would stabilize any residual liquid and solids in the tanks, fills an otherwise void area and prevents soil slumping from solvent tank collapse. This would leave the entire ORWBG with a low permeability native soil cap and proper contouring to better manage storm water with minimum maintenance.

3.4 Groundwater Contamination and Current Remediation Efforts

Groundwater contamination by constituents of the ORWBG is being addressed in a RCRA program for remediation of environmental impacts (Refs. 3.2 & 3.3) in land areas adjacent to the ORWBG complex. Of particular concern is the area adjacent to ORWBG designated as the Southwest (SW) Plume Area. Groundwater in this area outcrops to Fourmile Branch, which flows to the Savannah River. T and VOC's leaching from the ORWBG waste dominate the groundwater contaminations in the SW plume area. There is some evidence of low concentrations of hazardous metals (Pb and Hg). No other ORWBG waste constituent, in particular Cd, C-14, Tc-99, or TRU radionuclides (Np-237, Pu-238, Pu-239) have been detected in concentrations exceeding drinking water protection standards. A corrective program aimed at near-term reduction of T and VOC's has been initiated. Principal features of this program include containment by damming of the surface outcrop in a retention pond, and pumping to an upflow irrigation system for phytoremediation (transferring the T from the groundwater to the atmosphere). Localized high VOC's will be remediated by air spargers or recirculation wells, also transferring the VOC's from the aqueous stream to the atmosphere. Warning signs and access gates to restrict personnel entry to the seepage pond have been installed, and additional ICs are projected as necessary over a 100-year time period. Attenuation by sorption (absorption and adsorption on the clays of the soil and transfer to vegetation), biodegradation, dispersion and dilution, volatilization, and chemical reactions that facilitate remediation of groundwater contaminants will be monitored.

References for Section 3

3.1 *"Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-E",* Westinghouse Savannah River Company, Report Number WSRC-RP-98-4012, Rev 0, March 1999.

3.2 *"2000 Renewal Application for a RCRA Part B Permit, Savannah River Site",* WSRC-IM-98-30, March 2000 (E.8 Corrective Action Program for the Southwest Plume Area.

3.3 *"Environmental Assessment for the Interim Measures for the Mixed Waste Management Facility, Groundwater at the Burial Ground Complex at the Savannah River Site"*, DOE/EA-1302, December 1999.

4.0 Institutional Control of ORWBG

The most important factor for determining the human health risks from the ORWBG over the next 10,000 years is the future use of the ORWBG and the remainder of the SRS. For example, health risks posed by the ORWBG depend upon the spatial relationship between the buried waste and the potentially exposed public and workers. Protection of the public is more critical because the working population would have work-place limits imposed that would reduce consequences of this waste. Several SRS documents discuss the SRS lands remaining under Federal Government control for the indefinite future.

DOE, EPA, and SCDHEC have agreed to implement a process to list and ensure all controls are properly managed that were identified in the record of decision (ROD) for a closed waste unit (similar to the ORWBG). This requires a Land Use Control Assurance Plan (LUCAP) (Ref. 4.1) be prepared for SRS to contain procedures for all land use controls (LUC) and to ensure that they remain effective over the long-term. The Manager of DOE-SR has the responsibility to certify that all closed units are in compliance every 5 years and to notify EPA and SCDHEC of this compliance. The LUC's normally describe engineered controls, and both active and passive ICs. Examples of active IC are controlling access to disposal site, performing maintenance or remedial action at the site, controlling or cleaning up releases from the site, and environmental monitoring. Passive IC may include fencing and permanent markers to convey information on the restriction, public records and archives (including easement, deed notification, deed restriction, lease requirement, covenant, etc.), or Government ownership of the land and resources, etc.

Active and passive ICs are also addressed under long-term stewardship in the SRS Comprehensive Plan (Ref. 4.2). In this plan "long-term stewardship includes all activities, environmental monitoring, site maintenance, application and enforcement of institutional controls and information management required to protect human health and the environment from hazards remaining at DOE sites after cleanup is completed." Reference 4.2 identifies a key element of the SRS stewardship program to be the use of IC to ensure that land use restrictions are maintained. SRS has been subdivided into three land use zones. They are: General Support Zone, Site Industrial Support Zone, and Site Industrial Zone. The ORWBG is located in the Site Industrial Zone near the center of the Site, surrounded by a safety and security buffer area. The Site Industrial Zone contains all of the facilities that process, store, recover or decontaminate radioactive liquids, solid wastes, fissionable materials, or tritium.

Hazard management is a necessary part of long-term stewardship and Reference 4.3 describes two primary features: engineered and institutional controls. Engineered controls include actions to stabilize and/or physically contain or isolate the waste or its contaminants to prevent them from reaching man. ICs are legal or other non-engineering measures intended to affect human activities in such a way as to prevent receptors from reaching residual hazards in the waste.

Since these general principles of IC and stewardship have been established, they should be applied to the ORWBG analysis. Consistent with the above general plans for IC but realizing the current lack of specifics, the FG made the judgment that the lands of the present ORWBG and the lands between the ORWBG and the points of groundwater out-cropping into Fourmile Branch containing potential contamination from the ORWBG would remain under long term stewardship (active or passive IC) for as long as required to maintain safety of operating staff or the public.

Active IC will prevent the public from having access to SRS. The FG assumes that active IC will extend 150 to 300 years beyond completion of stabilizing the High Level Waste at SRS. With this assumption, active IC is maintained until 2175 or 2325 when the controls are reduced to passive IC. As required by the LUCAP process, deed restrictions and proper marking, fencing, etc. will be in-place to warn future people about the hazards that exist below the ground surface.

By the time that ICs move from active to passive, the FG no longer considers the human health risk from the entire 300 square miles of SRS to justify maintaining the entire site under government ownership. Lands that have less risk may be returned to other uses. Given this consideration, the FG assumes that the lands south of Fourmile Branch may be turned over for public use. The controls on the lands of the ORWBG and those between the ORWBG and Fourmile Branch should be more restrictive than those south of Fourmile Branch.

The analysis also identified a third important feature, not discussed above. Natural systems (clay content of the soil, groundwater flow rate and distance from streams) provide protection and barriers so the short-lived radionuclides decay away before the public is exposed to them. These natural features delay the migration of radionuclides. Long-lived radionuclides will eventually reach surface water and the population but only after a significant fraction of the original inventory decays. The exposure to contamination will be spread out over many generations due to the contaminants' dispersion in the groundwater. Each of these is considered in the analysis.

The FG analysis expands these general attributes for the ORWBG as needed to protect the health of the public currently residing near SRS and much later, if any public should move on to some SRS lands.

References for Section 4

4.1 *"Land Use Control Assurance Plan for the Savannah River Site",* Westinghouse Savannah River Company, Report Number WSRC-RP-98-4125, Revision 1.1, August 99.

4.2 *"SRS Long Range Comprehensive Plan",* US Department of Energy-Savannah River Operations Office, December 2000.

4.3 Draft *"Long Term Stewardship Study",* U. S. Department of Energy, Office of Environmental Management, Office of Long-Term Stewardship, Draft for Public Comment, October 2000.

5.0 Groundwater Transport and Health Effects for ORWBG Wastes

This section describes the COI transport from the ORWBG to the groundwater and eventually surface water and the potential impact on human health. Most of the information in this section is derived from Appendices C, D, and E of this report.

Amounts of contaminants of interest, both radionuclides and hazardous chemicals, were calculated using inventories and locations within the ORWBG as provided in the CMS/FS (Ref. 5.1). An appropriate mathematical model was generated and is described in Appendix C. This model provided averaged transport concentrations that were used to calculate appropriate stream concentrations of the pollutant. (The CMS/FS transport model determined the maximum concentrations and was considered too conservative to use to calculate the stream concentrations and health hazards.)

The model calculates a vertically averaged concentration over the plume thickness as a function of time and location, with the contamination moving in the direction of the aquifer flow. In other words, contaminant concentrations were spread across a horizontal plane source of the dimensions of the burial ground for all contaminants, with uniform flow through the vadose zone and the water table aquifer toward Fourmile Branch. The model assumed that movement of the contaminants was planar and not along a single straight line, and that the contaminants entered the creek along a plane and not at a single point. This assumption results in the calculation of the average concentration (of any contaminant) along that reach of the creek adjacent to the seepline. It used flow rate parameters defined in the CMS/FS. The transport mechanism for radionuclides and hazardous chemicals was assumed to consist of a four component system: (1) the contaminated soil of the burial ground, (2) the leachate moving downward through the vadose zone and entering the aquifer, (3) a plume in the aquifer which moves toward an exposure location where it ultimately enters Fourmile Branch, and (4) the mixing with Fourmile Branch and the Savannah River. This model was calibrated using the measured amount of tritium in Fourmile Branch since 1968. Calculated and measured values were in good agreement, as can be seen in Appendix C, an indication that the model is a good prediction of actual concentrations.

Numerous factors, including amount and the physical condition of material in the ORWBG burial trenches, the half-lives of the various isotopes, and the movement and soil characteristics, all affect how the materials flow through the natural system. Some nuclides, such as cesium-137, cobalt-60, strontium-90, and plutonium-238 will decay away before reaching Fourmile Branch. Because of its strong affinity to ORWBG soils, plutonium-239 won't appear at Fourmile Branch for approximately 32,000 years nor reach its peak for about 80,000 years. Nuclides that will reach Fourmile Branch, and ultimately the Savannah River, within the next 10,000 years, are tritium, technetium-99, iodine-129, carbon-14, neptunium-237, and uranium-238 and -235.

Appendix D provides a series of tables and figures to show when these radionuclides will reach Fourmile Branch and the concentration of each. Table 5-1 shows when maximum radionuclide concentrations will reach the seepline. The seepline is the point of groundwater seeping into Fourmile Branch. The time between when water reaches the seepline and when it is available for drinking water is short (on the order of days, not years). Table 5-2 shows similar information for non-radioactive chemical contaminants. Both tables show other contaminants that would be present in the water entering Fourmile Branch at the same time as the COI. Figure 5-1 shows the radionuclides reaching Fourmile Branch in graphic form. On that figure the year 1960 is the equivalent of 0 years.

Table 5-1
Maximum Concentrations of Radionuclides from Old Radioactive Waste Burial Ground at Fourmile Branch Seepline

Year	Radionuclide with Maximum Concentration in that Year	Concentration at Fourmile Branch Seepline (pCi/L)	Other Radionuclides present in the time period	Concentrations at Fourmile Branch Seepline (pCi/L)
1989	Tritium	870,000	Technetium-99	0.0026
2020	Technetium-99	44	Tritium	2,000
2160	Iodine-129	12	None	
2800	Carbon-14	840	Neptunium-237	0.49
7660-7740[1]	Uranium-238	0.54	Uranium-235	0.022
7660-7740	Uranium-235	0.022	Uranium-238	0.54

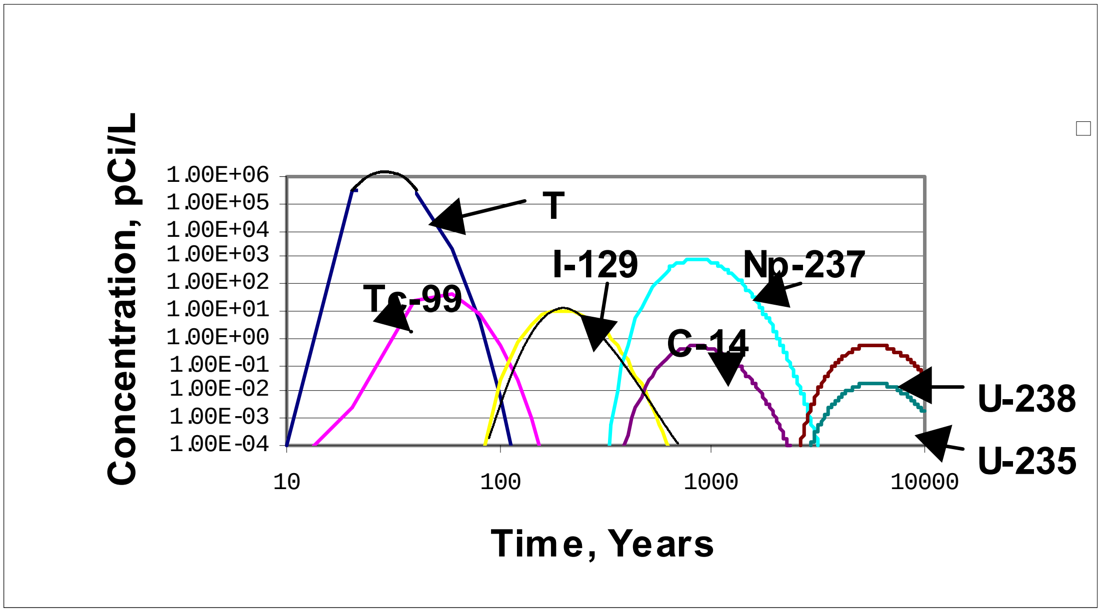
1 Both Uranium-235 and –238 concentrations peak between the years 7,660 and 7,740

Table 5-2
Chemical Release Periods

Chemical Releases	Start Time	Time of Peak Concentration	Peak Conc., Micrograms/ liter	End Time	Radionuclides in Water at Same Time
VOC	1988	2010	93	2060	T and Tc-99
Cadmium	2460	2960	0.33	3960	C-14, I-129, and Np-237
Mercury	2960	3560	1.4	4960	C-14 and Np-239
Lead	11960	17960	0.62	41960	U-238 and U-235

VOC = Volatile Organic Compound
T = Tritium
Tc = Technetium
C = Carbon
I = Iodine
Np = Neptunium
U = Uranium

Figure 5-1
Radionuclide Concentration in Fourmile Branch



Once pollutants (both radioactive and chemical) flow from the seeps into Fourmile Branch and to the Savannah River they are significantly diluted by branch and river water flows. Table 5-3 gives the dilution from the ORWBG to the Port Wentworth and Beaufort Jasper water intakes. Figure 5-2 shows a map of SRS with locations used in the calculations in Appendix D. Port Wentworth and Beaufort Jasper are off the map, about sixty miles down river. These drinking water plants are the first points below the Savannah River Site that river water is withdrawn for drinking water.

Table 5-3
Dilution Factors from the ORWBG seepline

Analysis Location	Stream/River Flow, M^3/yr	Dilution Factor, Volume at Location/Volume at Seepline
Seepline	2.22×10^6	1
Fourmile Branch	7.8×10^6	4
Road A	3.2×10^7	14
Mouth of Fourmile Branch	1×10^{10}	4500
Savannah River at 301 Bridge	1.06×10^{10}	4800
Port Wentworth Water Intake	1.2×10^{10}	5400

Tables 5-1 and 5-2 and Figures 5-1, 5-3, and 5-4 show the time frames and concentration of pollutants at the seep line. If a person were to get his or her full drinking water from a location on Figure 5-2, the dose commitment for that location is shown on Table 5-4. The table shows the dose from each radionuclide of interest and the total dose that an individual would receive if he drank all his water from that location for the period of one year. Figures 5-3 and 5-4 give the same information in graphic form. Figure 5-3 shows the doses at various times in the future at four different locations: in Fourmile Branch just below the ORWBG, at Road A, in the Savannah River at the mouth of Fourmile Branch, and at Port Wentworth water intakes. Figure 5-4 shows the dose rates at the same locations but for different times. Combined, the two figures show the impacts for the 10,000-year analysis period.

Figure 5-2
SRS Map Showing Location of Calculated Pollutant Concentrations

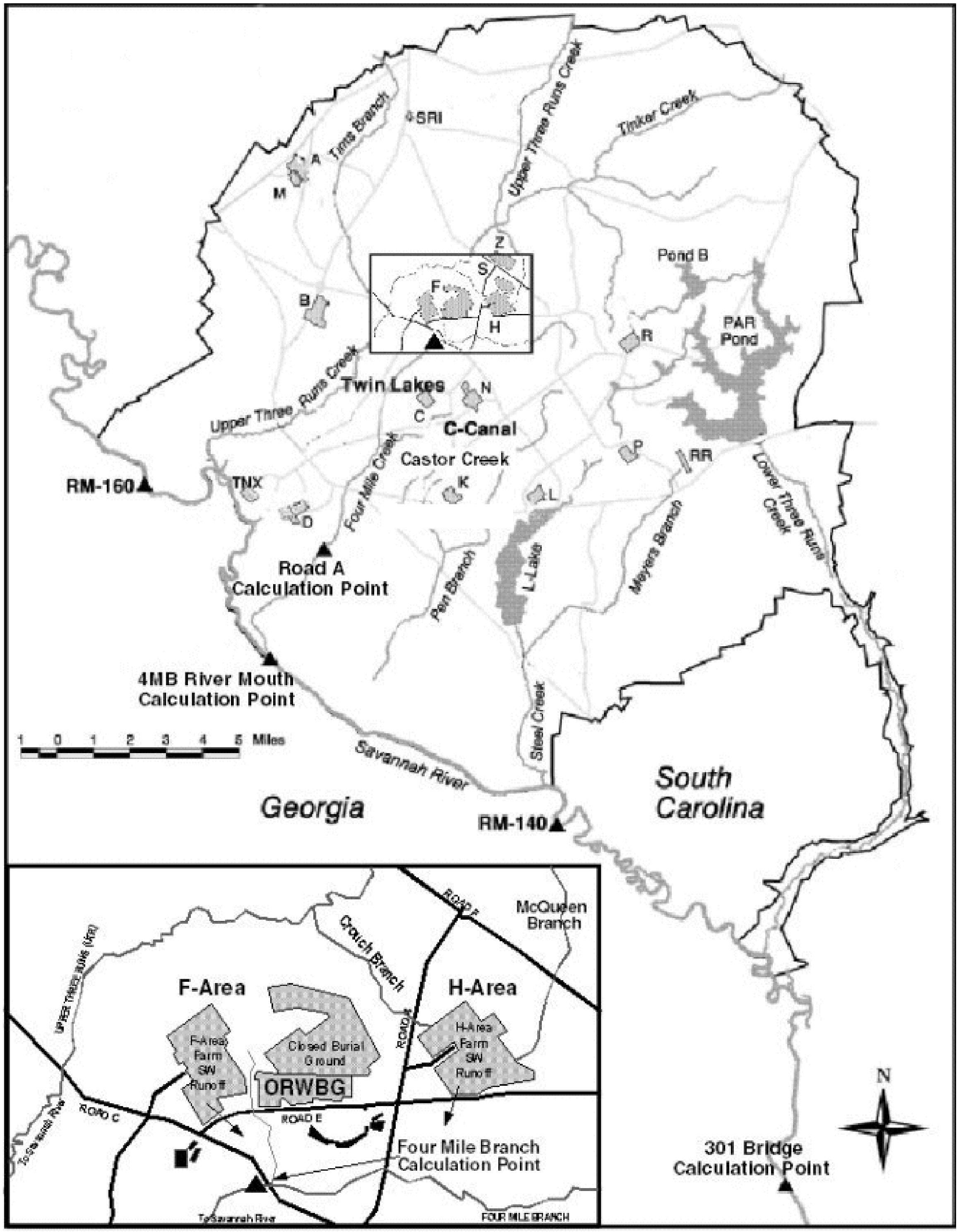


Figure 5-3
Dose Rate (mrem/yr) from Drinking Water Contaminated with ORWBG Releases
From the Years 1960 (0 years on Figure) to 2160 (200 years on Figure)

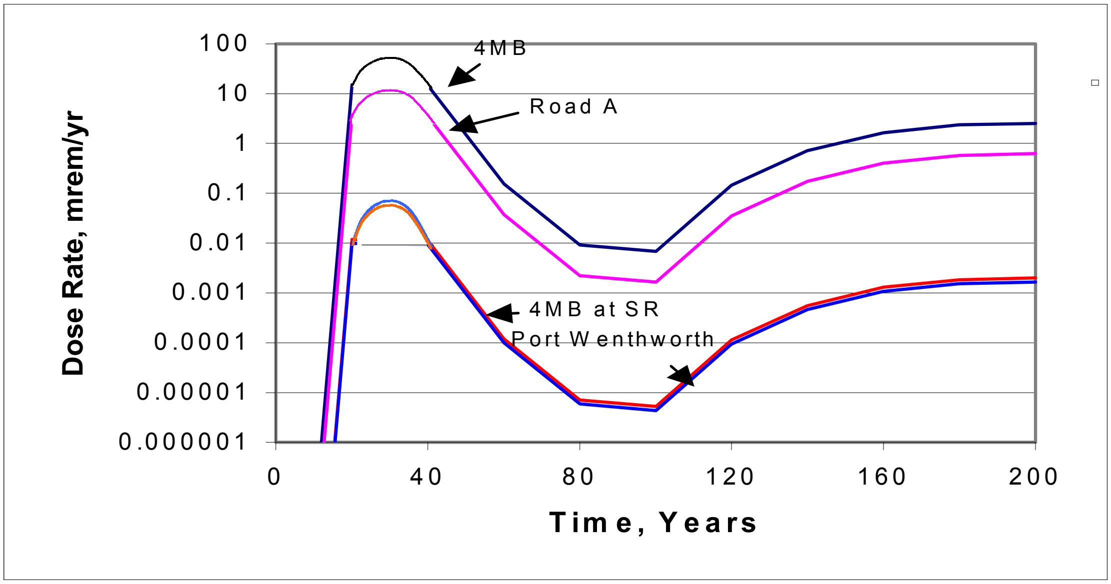


Figure 5-4
Dose rate (mrem/yr) from Drinking Water Contaminated with ORWBG Releases
From the Years 2060 (100 years on Figure) to 11,960 (10,000 years on Figure)

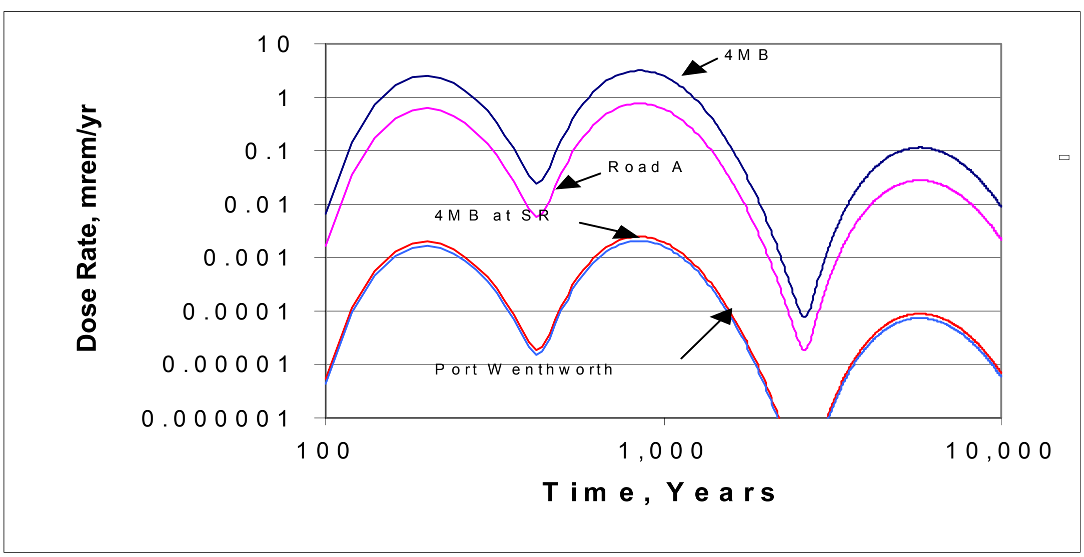


Table 5-4
Dose Rate from Water with Contaminants from ORWBG
Dose Rate, in mrem/yr

Year	Nuclide	Dose (mrem/yr)			
		Road A	Savannah River at Mouth of Fourmile Branch[a]	Savannah River at 301 Bridge	Port Wentworth Water Intake
2020	Technetium-99	0.012	4.0×10^{-5}	3.8×10^{-5}	3.3×10^{-5}
	Tritium	0.025	8.0×10^{-5}	7.5×10^{-5}	6.6×10^{-5}
	Total Dose[b]	0.037	0.00012	0.00011	9.9×10^{-5}
2060	Technetium-99	0.00015	5.0×10^{-7}	4.7×10^{-7}	4.2×10^{-7}
	Tritium	7.8×10^{-8}	2.5×10^{-10}	2.3×10^{-10}	2.1×10^{-10}
	Iodine-129	0.0015	4.8×10^{-6}	4.5×10^{-6}	4.0×10^{-6}
	Total Dose[b]	0.0017	5.8×10^{-6}	5.0×10^{-6}	4.4×10^{-6}
2160	Iodine-129	0.62	0.002	0.0019	0.0017
2360	Iodine-129	0.0078	2.5×10^{-5}	2.4×10^{-5}	2.1×10^{-5}
	Carbon-14	0.0002	$6.4x10^{-7}$	6.0×10^{-7}	5.3×10^{-7}
	Neptunium-237	$2.3x10^{-4}$	$7.5x10^{-7}$	7.1×10^{-7}	6.2×10^{-7}
	Total Dose[b]	0.0082	0.002	2.5×10^{-5}	2.2×10^{-5}
2460	Iodine-129	$2.8x10^{-4}$	9.0×10^{-7}	8.5×10^{-7}	7.5×10^{-7}
	Carbon-14	0.017	5.6×10^{-5}	5.2×10^{-5}	4.6×10^{-5}
	Neptunium-237	0.021	6.6×10^{-5}	6.2×10^{-5}	5.5×10^{-5}
	Total Dose[b]	0.038	$1.2x10^{-4}$	0.00012	0.00010
2560	Iodine-129	8.1×10^{-6}	2.6×10^{-8}	2.4×10^{-8}	2.2×10^{-8}
	Carbon-14	0.11	$3.5x10^{-4}$	$3.3x10^{-4}$	$3.0x10^{-4}$
	Neptunium-237	0.13	$4.2x10^{-4}$	$3.9x10^{-4}$	$3.5x10^{-4}$
	Total Dose[b]	0.24	$7.7x10^{-4}$	$7.2x10^{-4}$	$6.4x10^{-4}$
2800	Carbon-14	0.34	0.0011	0.0010	$9.2x10^{-4}$
	Neptunium-237	0.42	0.0014	0.0013	0.0011
	Total Dose[b]	0.77	0.0025	0.0023	0.0021
7660	Uranium-235	0.0011	3.2×10^{-6}	3.4×10^{-6}	3.0×10^{-6}
	Uranium-238	0.027	8.5×10^{-5}	8.1×10^{-5}	7.1×10^{-5}
	Total Dose[b]	0.028	8.9×10^{-5}	8.4×10^{-5}	7.4×10^{-5}
7740	Uranium-235	0.0011	3.6×10^{-6}	3.4×10^{-6}	3.0×10^{-6}
	Uranium-238	0.027	8.5×10^{-5}	8.1×10^{-5}	7.1×10^{-5}
	Total Dose[b]	0.028	8.9×10^{-5}	8.4×10^{-5}	7.4×10^{-5}

a Estimated based on flows at gauging stations above and below Fourmile Branch
b Dose from all ORWBG nuclides present in the water, not just the nuclides reported in this table

As indicated in Section 4 of this report, the Focus Group has made the judgment that for the next 150 to 300 years active institutional control will be maintained over the land of the present SRS and access will be limited and controlled. This judgment is consistent with present stewardship plans for SRS. Applying this condition, no individuals will be drinking the waters on the SRS. The Focus Group concludes the nearest water drinkers would be across the Savannah River from Fourmile Branch. After active IC transitions to passive IC, it is reasonable to assume water drinkers might utilize the waters of Fourmile Branch. The maximum dose from drinking Fourmile Branch waters would occur about 2800 years in the future. This dose rate would be approximately 0.77 mrem/yr with a 3.9×10^{-7} risk of developing a latent fatal cancer after one year of drinking the water and a lifetime risk (70 years) of 2.7×10^{-5} (See Appendix H for details).

Dose standards, at present, are set at 100 mrem/year for the general public. Air pathways are 10 mrem/year and drinking water pathways are 4 mrem/year. Assuming institutional controls, no member of the public will receive a dose that exceeds drinking water standards, now or at any time in the future, and no adverse health effects are expected from drinking water from Fourmile Branch.

References for Section 5.0

5.1 *"Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-E",* Westinghouse Savannah River Company, Report Number WSRC-RP-98-4012, Rev. 0, March 1000.

6.0 Surface Occupation of the ORWBG Site

Environmental remediation decisions for the ORWBG must consider risk of human occupation of the burial ground site over near and long-term time frames. Prevalent among these risks are the radiation exposures incurred by onsite workers in surveillance and maintenance operations during the time of active IC (assumed 150 to 300 years) and by members of the public with access to the site during subsequent times (up to 10,000 years in this analysis). This section projects radiation exposure for the on-site worker using ambient radiation monitoring. Radiation risks to members of the public, after the transition from active IC to passive IC and assuming failure of the passive IC controls, are estimated for exposures to individuals potentially occupying and performing agricultural activities on the site of the ORWBG. Occupancy of the site of the ORWBG during passive IC assumes failure of passive barriers (fencing, markers, public records and archival restrictions) imposed to restrict public access to and use of the burial site. The agricultural scenario establishes a chronic exposure for the year-round occupant of the ORWBG. Projection of the exposures for other scenarios is presented in the Intruder Analysis in Appendix F and in the CMS/FS (Ref. 6.1).

6.1 Near Term Radiation Exposures (during Active IC)

The radiation exposure from working on the surface of the ORWBG is no different than background radiation at other locations. On-site workers, during the period of active IC, are assumed to perform routine burial site maintenance activities, including inspection and repair of the ORWBG surface cap, service of perimeter monitoring wells, control of surface water runoff and resulting erosion, and upkeep of the prescribed vegetative cover. Ambient radiation monitoring of the ORWBG complex has shown radiation exposures in the range of 82 - 239 mrem/yr with an average of about 120 mrem/yr as measured by thermoluminescent dosimeters (TLD) recording beta-gamma radiation. These exposures are found in Reference 6.2. These exposures show no statistical difference from ambient background radiation (Ref. 6.3). Therefore, it can be assumed that workers receive no additional dose from radionuclides buried in the ORWBG. (For more detail, see Appendix H, Section H.3.)

6.2 Radiation Exposure during a Failure of Passive IC (after Cessation of Active IC)

The radiation exposure incurred by an occupant of the burial ground site after the time of active IC and assuming that passive IC controls have failed is influenced by two factors that potentially increase the risk of surface occupation: (1) erosion of the surface cap to the extent of direct exposure to waste constituents and (2) the presence of localized high concentrations of waste constituents (hot spots) to which the hypothetical site occupant could be exposed.

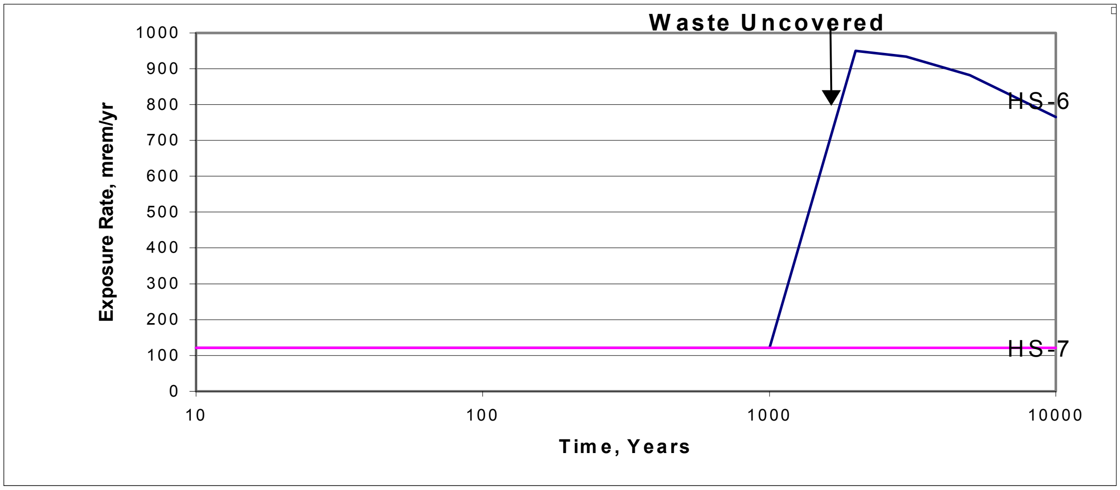
Concern over chronic exposure to an occupant of the burial ground site is centered on the fate of hot spot waste concentrations over extended time periods (up to 10,000 years). Within this time period, the potential for erosion uncovering the buried waste requires quantitative evaluation. The CMS/FS analysis uses an erosion rate of 1.4 mm/yr, which could penetrate the minimum 8-foot cap on the ORWBG in about 1,750 years. Before this time, surface radiation exposures similar to current measurements should prevail. After this time erosion of the burial ground cover would expose the waste and would significantly increase the chronic exposure of an occupant of the ORWBG. Analyses of projected exposure for hot spot concentrations as presented in the CMS/FS provide a measure of this increased exposure.

Detailed review of the data presented in the CMS/FS documentation has identified hot spots containing carbon-14 and plutonium-239 as the most significant potential contributors to radiation exposures if passive IC should fail. As stated in Appendix F, the hot spots containing these waste constituents would produce marked increases in dose commitment to occupants of the ORWBG between elapsed times of 1,000 and 3,000 years. (Reference 6.1 provides no data between 1,000 and 3,000 years.) These increased exposure rates are caused by the surface soils having been eroded away. These dose commitments result from inhalation and ingestion of radionuclides from the buried waste. For elapsed times greater than 3,000 years, the exposure rates decrease slowly, probably due to radioactive decay and/or transport of the waste from the hot spot by erosion. Other hot spot locations have relatively low projected exposure rates due to rapid depletion of the wastes by radioactive decay and leaching. These trends are illustrated in Figure 6-1 comparing projected inhalation of radionuclides from the long-lived Pu-239 in hot spots (called HS-6 in the CMS/FS) and hot spot HS-7 containing the short-lived T, Sr-90, and Cs-137. The data given on Figure 6-1 for HS-6 represents a maximum for the Pu-239 hot spots. The HS-7 data is representative of other areas of the ORWBG. HS-7, with an exposure rate of approximately 120 mrem per year for the entire 10,000 year analysis period, is equivalent to background. The hot spots identified in the CMS/FS comprise 13 percent of the total area of the ORWBG.

The potential for relatively high radiation exposure from surface occupation of the ORWBG site after active IC mandates remedial measures to impede erosion of the burial ground cap. Although the low probability of exposure (from failure of the passive IC) substantially reduces the projected risk, the high consequence of such an exposure suggests the advisability of erosion control. See Appendix H for a discussion of potential health risks.

Reduction of the rate of erosion of the cap is potentially achievable by adding a protective vegetative cover to minimize the erosion and prevent establishment of deep-rooted plants or burrowing animals on the cover. In one treatment scenario, the burial ground cap would be planted with two bamboo species, as planned for the E-Area Vaults. The bamboo species, once established, would grow six to eight feet tall and form a dense top cover shading the natural succession of native trees. This type cover is expected to reduce the soil erosion to a rate projected for a natural succession forest, equivalent to 0.007 mm/yr. At this erosion rate, several tens of thousands years would be required to uncover the ORWBG waste constituents.

Figure 6-1
ORWBG Surface Radiation Exposure



6.3 Health Effects from ORWBG Exposure

No health effects can be expected from working or living on the surface of the ORWBG because there has been no discernable radiation exposure attributable to the burial ground. If erosion is controlled, the maximum exposure would be about 120 mrem/yr and would all be due to natural background radiation.

If the surface soils erode away, and a person lived directly on the ORWBG waste for a year, the estimated 50-year committed dose could be approximately 810 mrem (16 mrem/yr). This incremental value is the difference between the dose of being over HS-6 for a full year less the dose he would have received anywhere else (930 – 120). The annual probability of a latent fatal cancer for this dose rate is 8.1×10^{-6} and a lifetime fatal cancer risk is 2.8×10^{-4}. Appendix H discusses these risks in greater detail.

6.4 Impact from Burrowing Animals and Insects

Most animals or insects do not penetrate the depth of cover that currently exists over the ORWBG. The only animal/insect intrusion of concern would be the Florida Harvester Ant (Ref. 6.4), which generally burrows down about 6 feet. Studies have shown that 5 percent of these ants can burrow deeper and could bring a small amount of contaminated soil to the surface. This small amount of contamination could cause small increases in exposure to individuals on the surface of the ORWBG. Due to the low probability of such occurrences, the Focus Group considers the risk of radiation exposure from this pathway to be too small to justify remedial action.

Referenced for Section 6

6.1 *"Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-G"*, Westinghouse Savannah River Company, Report Number WSRC-RP-98-4012, Rev. O, March 1999.

6.2 *"Savannah River Site Environmental Report for 1997",* WSRC-TR-97-00324, page 45, Westinghouse Savannah River Company, Aiken, SC and *"Savannah River Site Environmental Report for 1999",* WSRC-TR-99-00301, Westinghouse Savannah River Company, Aiken, SC.

6.3 *"Potential Human Health Risk from Low Level Radiation Doses",* by Tim Jannik, Presentation to the ORWBG Focus Group, May 31, 2000.

6.4 *"Relevance of Biotic Pathways to Long-Term Regulations of Nuclear Waste Disposal, Phase II",* Final Report, by D.H. McKenzie et al., Pacific Northwest Laboratory, Richland, WA, Report Number NUREG/CR-2675 or PNL-4241, 1986.

7.0 Consequence from Intrusion at ORWBG

7.1 Introduction

This section assumes that active IC are effective in preventing intrusion, occupation of the ORWBG lands and digging into the waste for 150 to 300 years. Successful transition to passive IC after this period assumes that the SRS stewardship program has identified and implemented restrictions for this long-term passive IC period, including fencing, permanent markers, and publicly recorded and archived restrictions (including easements, deed notification, deed restrictions, lease requirements, covenants, etc.). Passive controls will not require active maintenance (e.g., mowing, repair of washes of the surface, etc.) but should prevent occupation of the ORWBG and use of the groundwater between the ORWBG and Fourmile Branch.

The FG believes that the probability of failure of active IC for a period of 150 to 300 years is extremely unlikely. Therefore, the risk from this intrusion during that time was not developed. The health consequences of intrusion during the much longer passive IC period were evaluated. Probability for the failure of passive IC is not included in the evaluation but it is expected to be so low that the risk from this hypothetical intrusion scenario is negligible. However, the consequence of this hypothetical intrusion was estimated and is the subject of this section.

7.2 Intrusion Considered in This Analysis

As described in Appendix G, the FG considered two intrusion scenarios: 1) intrusion on the surface of the ORWBG and into the buried waste and 2) intrusion and use of the groundwater flowing from the ORWBG to Fourmile Branch. The analytical approach used for each of the scenarios is described in the following paragraphs.

The FG reviewed the intruder approaches used for the SRS Performance Assessments and the CMS/FS (Ref. 7.1). The FG decided to use the data from the CMS/FS intrusion analysis. (Appendix G describes these decisions in more detail.)

The approach used in this analysis assumes the following:

- A member of the public locates on the ORWBG,
- He digs a home basement (which goes into the buried waste) and spreads the contaminated soil onto the surface of the land,
- He establishes a garden in the contaminated soil, and
- He consumes the crops from this garden.

In the CMS/FS, this is called the agricultural scenario. Since the intruder has ignored one or more of the passive IC, the analysis assumes he is notified of the breach and leaves the ORWBG after one year. The assumptions in the analysis include:

- The inventory of radionuclides was decayed,
- The inventory of the radionuclides was not decreased by transport by infiltration of precipitation, and

- The cap on the ORWBG was assumed to erode at 1.4 mm/yr.

Each of these conditions affects the consequence analysis. The radioactivity is dependent on the time between when the radionuclides were buried and the intrusion. Assuming no transport by infiltration to groundwater maximizes the consequences of the analysis. The erosion of the surface of the ORWBG at a rate of 1.4 mm/yr exposes the waste in about 1,750 years. Eroding of the surface exposes more radioactive materials over time passes and maximizes the consequences of the intrusion. The time of the intrusion is important.

The human health consequence of drinking the groundwater leaving the ORWBG and Fourmile Branch is determined by examining the radionuclide release rate and transport in the groundwater as a function of time (as described in Appendix D) and health consequences from consumption of the water (Appendix E). Figure E-4 shows the multiple peaks in dose from consuming releases from the ORWBG.

7.3 Intruder Dose for Agricultural Scenario

Table 7-1 lists the total agricultural consequence (mrem/year) for all of the hot spots 300 years hence. (The names of the hot spots were shortened in this section from HS-100-1 to HS-1.) HS-1, 6, and 13 contain plutonium (Appendix G, Table G.2). HS-18, 19, and 20 have C-14 also identified in Table G.2. The radionuclide inventories in HS-12 and 16 do not substantiate the doses given in Table 7.1 (taken from Ref. 7.1). (The FG did not attempt to substantiate the doses given for these two hot spots.)

As can be seen from Table 7-1, the maximum 50-year committed dose for HS-16 is 14,300 mrem and for purposes of this discussion is assumed to be from Pu-239. This analysis assumed that the surface of the ORWBG would erode away at 1.4 mm/yr. If surface management control strategy, as recommended by the FG, is implemented the increases in dose observed in Table 7-1 after the 1,000 years, would not occur. The FG did not recalculate the consequences using this assumption but it would be expected to be lower and decrease as the Pu-238 decayed.

The maximum dose commitment for intrusion is for hot spot HS-16. As mentioned earlier, the FG does not find radionuclide inventory sufficient to support the 14,000 mrem dose rate after 3,000 years. However, the FG chose to use this value to calculate health risks. (Table G.2 shows that the radionuclide inventory in this hot spot is less than 100 curies after 300 years decay). These dose rate numbers are above current regulatory standards but should not cause a measurable risk.

Table 7-1
Intruder Dose for Agricultural Scenario,
50-year Committed Dose (mrem per year of exposure)

Time, Yrs	300	500	1,000	3,000	5,000	10,000	Hot Spot Inventory[a]
HS-1	95	110	190	390	380	340	Pu-239
HS-2	1	0	0	0	0	0	
HS-3	0	0	0	0	0	0	
HS-4	0	0	0	1	1	1	
HS-5	5	7	10	14	14	14	
HS-6	520	440	660	1,200	1,200	1,100	Pu-239
HS-7	7	2	2	3	3	3	
HS-8	0	0	0	0	0	0	
HS-9	92	6	7	9	9	9	
HS-10	580	130	4	1	1	1	
HS-11	0	0	0	0	0	0	
HS-12	0	24	380	1,500	1,400	1,300	
HS-13	2,400	2,000	2,700	3,900	3,700	3,300	Pu-239
HS-14	5	6	8	10	10	9	
HS-15	31	14	8	16	15	13	
HS-16	4,500	6,200	10,100	14,300	11,200	6,100	
HS-17	2	0	0	0	0	0	
HS-18	17	1	1	2	2	2	C-14
HS-19	2,300	3,800	7,400	13,000	10,100	5,500	C-14
HS-20	33	2	2	2	2	2	C-14
HS-21	107	15	4	5	5	5	

[a] Only inventory of predominant nuclide; but does not necessarily indicate radionuclide contributing to dose.

7.4 Intrusion into the Lands Between the ORWBG and Fourmile Branch

If an individual were to drink the contaminated groundwater between the ORWBG and Fourmile Branch, this dose would depend on when and where the intrusion occurred. If the intruder drank the contaminated groundwater from the geometric center between the ORWBG fence and the seep line for one year, the 50-year committed dose could be 55 mrem at about 600 years at the peak Np-237 and C-14 concentrations. The 50-year committed dose would peak again at 2 mrem at about 4,000 years because of U-238 and U-235 concentrations. The geometric center of the contamination plume was selected for this analysis to average the consequences of intrusion. (It is recognized that if the intrusion was closer to the ORWBG the peak concentrations would be higher at an earlier time. Conversely, the concentrations would be lower at later times and a locations nearer the creek.)

Both of the dose commitments assume that the intruder is made aware of his intrusion by the end of a single year and his consumption of the contaminated waters ceases. This couples the intrusion to passive IC on this land. The FG recommends passive IC be included on these lands in publicly recorded restrictions. The 55 mrem dose commitment that an intruder might get at 6,000 years could be calculated to result in an increase in the lifetime probability of 1.4×10^{-5} of contracting a latent fatal cancer. This assumes a conversion factor of 0.0005 latent cancers fatalities per person-rem per year (Ref. 7.2; page 25) and the dose commitment is adjusted for probable lifetime.

However, if no passive IC exists, the intrusion would most likely continue for more than a year. If the intruder drank contaminated water for a 70-year lifetime, he could receive a total dose commitment of 3.8 rem. and probability of a cancer death could increase to 9.6×10^{-4}.

It is unlikely for the two intruder consequences described above to cause adverse health effects.

References for Section 7

7.1 *"Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-G"*, Westinghouse Savannah River Company, Report Number WSRC-RP-98-4012, Rev. O, March 1999.

7.2 *"Limitations of Exposure to Ionizing Radiation",* National Council on Radiation Protection and Measurements, Report Number 116, 1993, Washington, DC.

8. Comparative Buried Inventories at DOE Sites

This section summarizes the inventories of shallow-buried transuranic (TRU), low-level radioactive materials and mixed low-level wastes (LLW and MLLW), tritium and hazardous waste (HW) at DOE sites. These are discussed in greater detail in Appendix I.

Section 3 of this report describes the COI's of concern in the ORWBG. The studies of the COI inventories buried in the ORWBG are well documented in the CMS/FS (Ref. 3.1). The inventory of 23,000 curies of alpha-emitting radionuclides comes from Table 2.3 of Ref. 3.1 and is shown in Table 8.1. The fraction of the 23,000 curies that is classified as TRU waste cannot be determined because there is no measurement of the weight of the waste. The definition of TRU-waste, as taken from federal legislation, is radioactive "waste containing more than 100 nanocuries/g of TRU alpha-emitting radionuclides with half-lives greater than 20 years" (Ref. 8.2).

Table 8-1
Radionuclides Buried in the ORWBG that Decay by Alpha Particle Emission

Radionuclide	Alpha Curies Buried
Pu-238	20,514
Pu-239	1,475
Np-237	1.99
U-235	0.6
U-238	14.8
Total	22, 907

To capture Atomic Energy Commission radioactive waste disposal practices involving alpha-contaminated materials that were in effect prior to the 1970s, DOE published a report on transuranic wastes buried at DOE sites (Ref. 8.2). Some latitude was taken in the report regarding alpha-contaminated waste and the formal definition of TRU waste but the site-to-site comparisons are on an equivalent basis. Allowing for radioactive decay since burial, SRS (Table 8-1 gives curies at burial) has about 18,300 curies of buried alpha activity. This is about one third the TRU waste buried at Hanford, 60 percent of the buried TRU at Idaho National Engineering and Environmental Laboratory (INEEL), and about the same amount as at Los Alamos National Laboratory (LANL). Nevada Test Site (NTS) and Oak Ridge National Laboratory (ORNL) TRU waste are fairly insignificant. As the overall risk from TRU buried wastes is estimated to be very low (Ref. 8.2) and as that in the ORWBG is a small fraction of the DOE total, the ORWBG FG concludes that: (1) the risk at ORWBG is so low as to be considered negligible; and (2) the TRU wastes in the ORWBG should remain buried.

Appendix I also compares disposal of LLW – radioactive only, MLLW – hazardous and radioactive, and HW – hazardous only. It includes the proposed method of disposal and the inventory. SRS MLLW represented 8 percent by volume of the MLLW that had been buried at DOE sites. MLLW burial at INEEL, ORNL, Portsmouth and Rocky Flats exceeded that buried at SRS. The buried inventory at SRS of LLW represent 16 percent by volume of the LLW that had been buried at DOE sites. LLW buried at Oak Ridge exceeds that buried at SRS. Reference 8.3 presents the lifetime maximum exposed individual latent cancer fatality probability for the LLW disposal (as the No Action Alternative) at SRS as $4x10^{-6}$. At Hanford and Oak Ridge, the same probabilities are $4x10^{-5}$ and $2x10^{-7}$, respectively. The ORWBG FG concludes that the ORWBG LLW and MLLW are comparable to those at other DOE sites and should be left in place.

Within the DOE complex, tritium-contaminated plumes of groundwater are being managed in various ways (Ref. 8.1). At SRS, tritium-contaminated groundwater is the most significant short-term regulatory problem for the ORWBG. It is not a human health problem. The ORWBG FG concludes that monitored natural attenuation (MNA) with an appropriate mixing zone is a sufficient management method for tritium-contaminated ground water.

Hazardous waste (HW) consists of non-radioactive waste materials. The RCRA definition of HW is any solid waste that exhibits the characteristics of ignitability, corrosivity, reactivity, or toxicity, or which has otherwise been determined to pose a hazard and which has been designated by the RCRA as a listed HW. RCRA defines a "solid" waste to include solid, liquid or contained gas. (Ref. 8.3) The HW constituents in the ORWBG given in Appendix D include VOC, cadmium, mercury and lead. The VOC's from the ORWBG that have entered the groundwater are primarily trichloroethylene (TCE) and tetrachloroethylene (PCE) (Ref. 8.4). Other VOC of concern at the ORWBG are toluene, trimethybenzene and xylene (Ref. 8.5).

Other DOE sites have hazardous wastes concentrations in groundwater exceeding standards, although the specific wastes differ among the sites. The FG concludes that SRS HW problems are similar to those at other DOE sites.

The ORWBG FG's general conclusion is that the COIs buried in the ORWBG are comparable to those that have been or will be buried at other DOE sites, and that the ORWBG COIs should be left buried because they are unlikely to cause human health risk.

References for Section 8

8.1 *"Long-term Stewardship Program Perspectives"*, Rod Rimando, US DOE-SROO, Old Radioactive Waste Burial Ground Public Focus Group Meeting, December 6, 2000.

8.2 *"Buried Transuranic- Contaminated Waste Information for U.S. Department of Energy Facilities"*, US Department of Energy, Office of Environmental Management, June 2000. (www.em.doe.gov/integat/buriedtru.html)

8.3 *"Final Waste Management Programmatic Environmental Impact Statement for Managing, Treatment, Storage, and Disposal of Radioactive and Hazardous Waste",* DOE/EIS-02000-F Vol. I, US Department of Energy, Office of Environmental Management, May 1997.

8.4 "*Environmental Assessment for the Interim Measures for the Mixed Waste Management Facility Groundwater at the Burial Ground Complex at the Savannah River Site"*, DOE/EA-1302, US Department of Energy, Savannah River Operations Office, December 1999.

8.5 "*Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-E",* Westinghouse Savannah River Company, Report Number WSRC-RP-98-4012, Rev 0, March 1999.

9.0 Applicability of Drinking Water Standards

9.1 US Environmental Protection Agency (EPA)

The Federal Safe Drinking Water Act grants EPA the authority to protect the quality of public drinking water supplies by establishing primary drinking water regulations. The EPA has delegated authority for enforcement of drinking water standards to the states. Regulations at 40 CFR 141 (Ref. 9.1) specifies maximum contaminant levels, including those for radioactivity, in public water systems, which the EPA generally defined as systems that serve at least 15 service connections or regularly serve at least 25 year-round residents.

The 1976 regulations specify that the annual concentration of beta and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the total body or any internal organ greater than 4 millirem/year (mrem/yr). The man-made beta-photon concentrations yielding 4 mrem/yr are calculated using National Bureau of Standards (NBS) Handbook 69 (Ref. 9.2) and a methodology that incorporated the International Commission on Radiological Protection (ICRP)-2 (Ref. 9.3) dose model from the 1950's. The total alpha particle maximum concentration level (MCL) activity is 15 pCi/L, excluding radon and uranium. The MCL's for tritium and strontium-90 are 20,000 pCi/L and 8 pCi/L respectively. The MCL for radium-226 and radium-228 is a total of 5 pCi/L. The MCL for uranium is 30 micrograms/liter (μg/L) (Reference 9.1).

Reference 9.4 provides tables specifying the concentrations of man-made radionuclides causing 4 mrem/yr doses calculated using the data in NBS Handbook 69 (Ref. 9.2), assuming
2 liters/day drinking water intake rate. The concentrations applicable to the ORWBG radionuclide COIs are given in Table 9-1.

Table 9-1
MCLs for Radionuclide COIs (pCi/L)

Tritium, H-3	20000
Carbon (C)-14	2000
Cobalt (Co)-60	100
Strontium (Sr)-90	8
Technetium (Tc)-99	900
Iodine (I)-129	1
Cesium (Cs)-137	200
Neptunium (Np)-237	15
Plutonium (Pu)-238	15
Plutonium (Pu)-239	15
Uranium (U)	30 μg/l

9.2 South Carolina Water Classifications & Standards

EPA has delegated primary water standards enforcement authority to South Carolina Department of Health and Environmental Control (SCDHEC) for public water systems in South Carolina. SCDHEC has established ground and surface water classifications and standards under R.61-68 (Reference 9.5) and primary drinking water regulations under R.61-58 (Reference 9.6). These South Carolina water quality standards are the groundwater and surface water performance standards applicable to the ORWBG. Reference 9.5 establishes for all State waters, surface waters and groundwaters, the State's official classified water uses and establish general rules and specific numeric water quality standards for protected classified waters and existing water uses. Where surface waters are not classified by name in Ref. 9.5, the use classification and numeric standards of the stream/river to which they are a tributary is applied. Thus, since the ORWBG groundwater has not been given an exception as allowed in the regulation, SRS streams have the same standards as the Savannah River although no one drinks the water. The MCLs for inorganic chemicals are:

Cadmium	0.005 mg/l	(Ref. 9.6)
Mercury	0.002 mg/l	(Ref. 9.6)
Lead	0.015 mg/l	(Ref. 9.1)

There are no established limits for VOCs as such but Ref. 9.5 gives limits of .005 mg/l each for trichloroethylene and tetrachloroethylene, major constituents of ORWBG VOCs (see Appendix I). The radionuclide MCLs for State waters are those adopted as primary drinking water standards by EPA (Ref. 9.6), see Table 9-1 above.

South Carolina allows, "A region or zone (called a mixing zone) in which specified water quality standards and classified uses are not applicable may be allowed by the Department." For surface waters, the mixing zones do not always meet chronic criteria. For groundwater the mixing zone "must exhibit the following characteristics: be solely within the bounds of SRS property; measures have been taken or commitments made to minimize addition of contaminants; the groundwater in question is confined to a shallow geologic unit which has little or no potential of being an underground source of drinking water, and discharges or will discharge to surface water without contravening the surface water standards; the contaminants in question occur on the property of SRS, and there is minimum possibility for groundwater withdrawals (present or future) to create drawdowns such that contaminants would flow off-site; and the contaminants are not dangerously toxic, mobile, or persistent." (Ref. 9.5).

9.3 Discussion

The first water system intake using the Savannah River water to supply drinking water is downstream of the Fourmile Branch in the Savannah River at the Port Wentworth drinking water plant. At that point there has been sufficient dilution of ORWBG radionuclide COIs to reduce all concentrations to levels below the radionuclide MCLs, see Table 9-2. (Table 9-2 information is taken from the data given in Appendix D.) Thus the ORWBG Focus Group concludes that EPA's drinking water regulations do not apply to radionuclide COIs from ORWBG on the SRS property.

Table 9-2
Maximum Concentrations from ORWBG
At Port Wentworth Water Intakes

Constituent of Interest	Concentration at Port Wentworth Water Intake	Year of Maximum Concentration [a]
Tritium	130 pCi/L	2000
Technetium (Tc-99)	$3x10^{-2}$ pCi/L	2020
Iodine (I-129)	$7x10^{-3}$ pCi/L	2160
Neptunium (Np-237)	$1.1x10^{-4}$ pCi/L	2560
Carbon (C-14)	$1.7x10^{-1}$ pCi/L	2560
Uranium (U-238)	$3.5x10^{-4}$ pCi/L	7660
Plutonium (Pu-239)	$4.5x10^{-4}$ pCi/L	80000
Mercury (Hg)	$8.8x10^{-4}$ μg/L	2120
Lead (Pb)	$4.0x10^{-4}$ μg/L	18000
Cadmium (Cd)	$2.1x10^{-4}$ μg/L	2960
VOC	$6x10^{-2}$ μg/L	2010

[a] See Section 5, Table 5-4.

If a mixing zone that includes the groundwater plume from the ORWBG, the surface drainage from the plume seep line to Fourmile Branch and the entire length of Fourmile Branch to its discharge into the Savannah River were applied during the operation of SRS and during the period of Active IC, the South Carolina MCLs for "State waters" would not be exceeded. The ORWBG FG recommends that such a mixing zone be authorized by SCDHEC during the remainder of SRS operation and during the period of active Institutional Control.

Because present access restrictions cannot be assumed for perpetuity, the ORWBG FG recommends a changed mixing zone be applied during passive IC. The mixing zone should be measured at the Road C monitoring point for this latter condition. This mixing zone would then includes the groundwater plume from the ORWBG, the surface drainage from the plume seep line to Fourmile Branch and the initial dilution of the surface drainage in Fourmile Branch. (This would then be an appropriate point for the South Carolina MCLs for "State waters" to be measured. The ORWBG Focus Group recommends that such a mixing zone be authorized by SCDHEC during the period of passive Institutional Control.)

In support of these recommendations the following are noted:

a. The NRC has established an exposure limit to the public of 100 mrem/yr from all paths (including drinking water) for its licensees, 10CFR20.

b. The EPA/SCDHEC drinking water MCLs are based on agency understanding of health risk information as of the 1950s-1960s. The dose models used in preparing Handbook 69 (Ref. 9.2) and ICRP Publication 2 (Ref. 9.3) were defined in terms of the annual dose equivalent to the critical organ; the critical organ could be the total body or any internal organ (Ref. 9.4). Reference 9.4 discusses more recent dose calculation methodology, including a 1991 proposed method based on a 1977 ICRP report (Ref. 9.7) which normalizes radiation doses and effects on a whole body basis using effective dose equivalent (EDE) (4 mrem EDE/yr). Using weighting factors specified by the 1977 ICRP report and one prepared in 1979 (Ref. 9.8) and changing to a proposed limit of 4 mrem EDE/yr, EPA was able to derive activity concentrations that correspond to a more uniform level of risk. However, EPA interpreted that the 1996 Safe Drinking Water Act Amendments required the same or greater protection against potential human health effects whenever the Agency proposes to modify an existing MCL for any contaminant (Ref. 9.4). This requirement was not applied in 1991, and now compels EPA to reevaluate the protection afforded by 1991 proposed MCLs. Thus, the current drinking water MCLs remain at the 1976 levels.

c. The dose commitment factors used in Section 5 and Appendices C and E are based on the 1977 and 1979 ICRP reports' methodology and use the EDE established in that work. The comparison between MCLs to give 4 mrem/yr (EPA/HB69, ICRP 2) and 4 mrem EDE/yr (ICRPs 1977/1979) for 2L drinking water per day is given in Table 9.4, below:

Table 9.4
Comparison of MCLs, pCi/L

Radionuclide	EPA (Ref. 9.2)	ICRP (Refs. 9.7 and 9.8)
H-3	20000	85500
C-14	2000	2600
Co-60	100	530
Sr-90	8	40
Tc-99	900	4000
I-129	1	20
Cs-137	200	53000
Np-237	15	1.2
Pu-238	15	17
Pu-239	15	15

Appendix C used dose conversion factors recommended in EPA's Federal Guidance Report 11; this is the contemporary method for estimating doses and is consistent with the approach outlined by DOE Order 5400.5. This approach is also consistent with the approach used in the annual SRS Environmental Reports, as mandated by DOE Order 5400.5.

References for Section 9

9.1 "*National Primary Drinking Water Regulations",* 40-CFR-141, US Environmental Protection Agency.

9.2 "*Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air or Water for Occupational Exposure",* NBS Handbook 69 as amended August 1963, US Department of Commerce, June 1959, August 1963.

9.3 "*Report of Committee II on Permissible Dose for Internal Radiation"*, ICRP Publication 2, International Commission on Radiological Protection (ICRP), 1959.

9.4 "*Radionuclides Notice of Data Availability, Technical Support Document",* Office of Ground Water and Drinking Water, US Environmental Protection Agency, March 2000.

9.5 "*Water Classifications & Standards (R.61-68), Classified Waters (R.61-69)"* Bureau of Water, South Carolina Department of Health and Environmental Control, June 1998.

9.6 "*State Primary Drinking Water Regulations: R.61-58",* Bureau of Water, South Carolina Department of Health and Environmental Control, February 2000.

9.7 "*Recommendations of the International Commission on Radiological Protection*". ICRP Publication 26. Oxford: Pergamon Press (1977) [ICRP, 1977].

9.8 "*Limits for Intakes of Radionuclides by Workers'*. ICRP Publication 30, Part 1. Annals of the ICRP Vol. 2. (3/4). Oxford: Pergamon Press (1979) [ICRP, 1979].

9.9 "Questions on Dose Conversions for Drinking Water Standards", e-mail from Patricia Lee to Lee Poe, February 26, 2001.

9.10 "*EPA's Federal Guidance Report No. 11"*, K.F. Eckerman, A. B. Wohlbarst, and A.C.B. Richardson, Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion, Federal Guidance Report No. 11, EPA-520/1-88-020, U.S. Environmental Protection Agency, Washington, D.C., 1988.

Long Range Analysis of the Need for Cleanup and Closure of the Old Radioactive Waste Burial Ground

- Human Health Risk Analysis -

Appendices

Appendix A.

ORWBG Focus Group Membership

Karen Patterson*, CAB Member – Administrative Lead from 12/8/98 to 3/15/00, then public member.
Jimmy Mackey, CAB Member – Public member until 3/15/00 then Administrative Lead to the present.
Lee Poe, Public – Technical Lead

Public Members:

Todd Crawford
Mike French (Distribution only)
Ann Loadholt (CAB Member until 3/15/00)
Gene Rollins
William Willoughby, CAB Member
Gerald Devitt (CAB Member starting 1/23/01)
Bill Lawless (CAB Member until 3/15/00, then Public)
Bill McDonell
Wade Waters, CAB Member

Regulators:

Julie Corkran, EPA
Ken Feely, EPA
Keith Collinsworth, SCDHEC
Shelley Sherritt, SCDHEC

Technical Support:

Jim Cook, WSRC
Mike Griffith, BNFL
Joe Price, WSRC
Rod Rimando, DOE
Don Toddings, BSRI
Sonny Goldston, BNFL
Ed McNamee, BSRI
Tom Rehder, WSRC
Carl Strojan, SREL
Elmer Wilhite, WSRC

Administrative Support:

Gerri Flemming, DOE
Jim Moore, WSRC

* Karen Patterson was elected CAB Chair and relinquished her position as the Administrative Lead on 3/15/00.

Note: Those names in **bold** attended a majority of the meetings.

Appendix B.

Meetings/Subjects of FG Deliberations

Date:	Location:	Subjects:
9/16/98	N. Augusta Community Center	DOE presented the background and status of the CMS/FS at a public meeting.
11/12/98	TetraTech NUS Building, Aiken	Those individuals interested in being on the FG met to receive a briefing on the ORWBG and define the public FG charter.
11/17/98	Adam's Mark Hotel, Columbia	The CAB unanimously adopted Recommendation #71 that recommended that SRS, EPA, and SCDHEC provide dedicated representatives and technical support to the public FG to ensure its effectiveness.
12/8/98	N. Augusta Community Center	WMER Subcommittee meeting the FG members met to determine the date of the next FG meeting and received a strawman of the scope of work for the FG.
1/4/99	Aiken Federal Building	The background of the FG was reviewed. A facilitator guided the FG through the process of defining their goal. A thumbnail description of nineteen suggested tasks was provided. The availability of information was discussed.
1/13/99	SRS, Building 724-7E	The FG met for a tour of the ORWBG and seepage area. WSRC distributed copies of ten documents as well as maps related to the ORWBG. The handouts included a crosswalk of the nineteen tasks identified by the FG against the source document list. Four initial tasks were identified along with a task team lead. Members of the FG were assigned to each task team.
3/17/99	Aiken Federal Building	The task team leads reviewed the status of their teams. WSRC reviewed the groundwater flow and flow paths and rates consistent with past studies. WSRC also gave a presentation on the Feasibility Study for the ORWBG.
4/14/99	Aiken Federal Building	The task team leads gave an update of their teams status. EPA gave a presentation on the drinking water standards.

Appendix B (Cont.)

Meetings/Subjects of FG Deliberations

Date:	Location:	Subjects:
5/5/99	Aiken Federal Building	The FG discussed two draft motions. - Corrective Measures Study/Feasibility Study (CMS/FS) for the ORWBG (Recommendation # 86) - Proposed Permit Modifications, Mixed Waste Management Facility at SRS Under South Carolina Hazardous Waste Management Regulations and RCRA (Recommendation # 87)
5/19/99	Aiken Federal Building	Two draft motions were reviewed and approved for forwarding to the WMandER Subcommittee: - Corrective Measures Study/Feasibility Study for the ORWBG - Proposed Permit Modifications, Mixed Waste Management Facility at SRS Under South Carolina Hazardous Waste Management Regulations and RCRA A request for an independent study of the CMS/FS was reviewed and approved
6/2/99	Aiken Federal Building	Presentations were given on the key features of the intruder analysis used in CMS/FS Report: Methodology/Results/Conclusions/Impacts. An overview was given for the CMS/FS groundwater modeling with an emphasis on assumptions and impacts. The FG reviewed the alternatives considered. Results of the Composite Analysis were presented. Potential applicability to the FG was discussed. The FG approach for groundwater transport analysis and consequence to man was reviewed. It was determined that a White Paper would be written as a precursor to a recommendation that there was no need for a clay cap other than for several hot spots.
9/29/99	Aiken Federal Building	WSRC presented the phytoremediation plan to be used as the interim action on SW plume. The FG received an update on the CMS/FS Comments/Impacts, status of the RCRA Permit modifications for southwest groundwater plume, and the Proposed Plan. The FG reviewed the responses to the CAB Recommendation # 75 Interim Corrective Measures Southwest Plume From ORWBG and developed a path forward. They also heard the status of the CAB ISPR.
12/15/99	Aiken Federal Building	The FG learned that the ERDA of Georgia Universities had been selected as the ISPR. Dr. Ratib Karam was the team lead for ERDA. A briefing on the status of the 70% removal of tritium at the SW plume using phytoremediatioin was discussed. In discussing the effectiveness of removing VOC from the SW plume it was felt there would have to be a 22% reduction of the VOC's to meet the regulatory standard 900 feet from the point of exposure. The RCRA Permit allows a phased approach. Phase one is to reduce the tritium flux to Fourmile Branch by 70% in the near term. Phase two would evaluate phase one and

Appendix B (Cont.)

Meetings/Subjects of FG Deliberations

Date:	Location:	Subjects:
12/15/99 (cont.)		perform further actions to eventually achieve tritium concentrations below the drinking water standard. Phase three would be to perform evaluations and modifications to improve effectiveness. The FG received an update on the CMS/FS schedule. A general discussion on IC concluded that it was prudent to consider active IC for a period of 100-years beyond cessation of active operation, until 2138.
1/5/00	SRS, Building 703-41A	The FG held an all day meeting on Site with the members of the ISPR team. The purpose was to get to know each other and educate the ISPR concerning the ORWBG. The FG informed the ISPR of their goal and expected results. Presentations were given on background of the ORWBG; CMS/FS, the Proposed Plan (PP) and the Record of Decision (ROD); the RCRA and CERCLA actions; RCRA interim action; and the Composite Analysis. All members went on a tour of the ORWBG. After the tour and presentations, open discussions were held to help answer any of the ISPR's questions. The ISPR reviewed their path forward.
2/9/00	Aiken Federal Building	The FG discussed a recommendation by one of the members of the ISPR team, Ward Wicker. Dave Amick, Science Applications International Corporation (SAIC) reviewed the status of the Hot Spots. It was mentioned that the probable path forward for the Old Solvent Tank Hot Spot is grouting the tanks. Probable solution for the Mercury Hot Spot is a cap as with the rest of the burial ground. The strategy is to develop and evaluate remedial alternatives for the 8 radioactive COI Hot Spots from the 500-year map. A presentation was given on the disposal of current waste. A presentation on IC stated that for long-term stewardship of the ORWBG, there were two controls; engineering controls such as caps and fences, and IC such as records and zoning. It was stated the SRS policy is to maintain the site boundary in perpetuity. Maintain in perpetuity means ownership by DOE or some other federal department.
3/15/00	Aiken Federal Building	The FG reviewed the draft ISPR Phase I Report. It was determined the report was extremely technical and required additional clarification. Comments were generated and sent to the ISPR Team Lead for clarification or inclusion in the report.

Appendix B (Cont.)

Meetings/Subjects of FG Deliberations

Date:	Location:	Subjects:
4/19/00	Aiken Federal Building	There was discussion on the original risk calculations based on dose, dose reduction and cost. Dr. Karam, the ISPR Team Lead, gave a presentation on a Phase 2 draft ISPR report. It was requested that the final ISPR report due in June contain calculated health consequences. A presentation was given on the Mixed Waste Management Facility Southwest Plume Area Corrective Action Plan. The objectives and components of the plan were discussed. The FG was of the opinion that the interim action was not needed to protect human health.
5/31/00	Aiken Federal Building	The FG received a presentation on facts related to C-14 as well as the C-14 reported in the SRS Composite Analysis. The peak compliance dose was reported as less than the DOE limit. The FG felt that C-14 was not a long range concern. The status of the CMS/FS schedule was reviewed. Costs of the alternatives were reviewed. The ISPR status was reviewed. Future meetings and agenda topics were discussed.
7/12/00	Aiken Federal Building	Comments on the draft ISPR report were discussed. Three individuals had sent in comments and they were reviewed. The comments were sent to the ISPR Team Lead for consideration in the final report. A presentation was given on the environmental impacts from the interim action on the SW plume. The results for tritium released to the river or to the atmosphere for the total population was the same, 0.5 person-rem. Tritium released to the river was N/A for onsite worker/populations because they don't drink or get into the water. The views on closure of CAB Recommendation # 106 (RCRA Permit Modification for the Mixed Waste Management Facility at SRS) were discussed. The FG felt the CAB should close the recommendation but agree to disagree that the action is not needed, necessary or cost effective. The path forward was discussed.
8/2/00	Hampton Inn, Aiken	Dr. Karam attended to discuss the comments to the draft ISPR Report sent in by the FG. The resolution of the comments were to be incorporated in the final report available in approximately two weeks. A presentation on intruder analysis in the Performance Assessment reviewed the scenarios considered. The FG was presented the differences in intruder analysis in the Performance Assessment and the CMS/FS. For the CMS/FS, the actions considered to resolve the intruder analysis were bio-barriers and intruder barriers. The intruder concepts of the National Academy of Science (NAS), NRC, and EPA were reviewed. The NAS proposed not looking at the consequence to the intruder breaking the law, but the consequence of intrusion damage to the barrier on the functional intent of the facility. The approach for intruder analysis in the FG work was discussed. It was stated that under DOE Order 5400.5, DOE couldn't relinquish control of the OWRBG because of the inventory and therefore, it may be under perpetual control. It was decided that the FG should look at what other sites are doing for IC.

Appendix B (Cont.)

Meetings/Subjects of FG Deliberations

Date:	Location:	Subjects:
8/30/00	Hampton Inn, Aiken	The FG reviewed the work completed by the FG related to intruder analysis over the hot spots. Health effects for the intruder scenario were reviewed. There was discussion that a small amount of radiation may be good for a person. The status of the CMS/FS and Proposed Plan (PP) was reviewed. Comments from the ER Committee on the ISPR report were reviewed. Key thoughts on the development of the FG Final Report was discussed. The path forward and agenda items were reviewed.
9/13/00	Aiken Federal Building	The comparative doses from the SRS and ORWBG releases was discussed. The FG reviewed the individual comments made in the ISPR Final Report to see if they had been incorporated. It was requested that the individuals that commented be called to confirm the answers to their comments were acceptable. A draft outline of the FG Final Report was handed out for review.
10/11/00	Aiken Federal Building	The status of the comments to the ISPR Final Report was reviewed. FG members were assigned to write up sections of the draft ORWBG Final Report. Appendices were to be completed by the end of November. A presentation was given of the findings on the various organizations that look at the various regulatory standards to give an understanding of the complexity and confusion that exists related to regulatory standards. The FG commented and agreed on the letter for closure of CAB Recommendation #106.
11/8/00	Aiken Federal Building	The FG agreed that the contract with the ISPR Team was complete. A review was given of the deep borrowing animals and roots analyzed in the Performance Assessment. It was determined that a combination of two species of bamboo were considered as the final vegetation layer that would keep out invasive animals and plants. The status of the work being done at the ORWBG was reviewed. Drafts of the sections completed on the draft ORWBG Final Report were reviewed. There was a discussion on the media-raised question of there being ten times more plutonium buried around the DOE complex than had originally been claimed. It appears that the buried plutonium has a substantially higher fraction of the total curies than was previously thought. DOE was asking NAS to review the plutonium issue.
12/6/00	Aiken Federal Building	A review was given of the closure actions at other DOE Sites. There are 113 geographic sites of which 65 have been closed. Of 9,700 ER release units, 3,195 are complete. In the remediation/completion phase, 4,124 complete. At SRS there are 515 ER units; 238 are in assessment phase. 277 are in the remediation/completion phase. Units with transuranic-contaminated material and radioactive material were reviewed. Nationally here are 22 units with monitored natural attenuation. Action being considered with regulators on closure and post-closure was discussed. Evaluation methods to determine effectiveness of the

Appendix B (Cont.)

Meetings/Subjects of FG Deliberations

Date:	Location:	Subjects:
12/6/00 (cont.)		interim action was discussed. A review was given of the status of the final draft report.
1/17 /01	Aiken Federal Building	The sections of the draft Final Report were reviewed and commented on. Sections of the document previously unassigned were assigned.
2/13/01	Aiken County Council Building	Drafts of the sections of the Final Report that were complete were reviewed. There was a discussion of the path forward.
3/13/01	Aiken Federal Building	The status of phytoremediation was reviewed. The initial goal for reduction in concentration was 25%. The immediate reduction in concentration was 50 to 65%. The irrigation system is over 29 acres and will operate 8 minutes a day in cold months and 30 minutes a day in hot months. The cost was $1.2 million. Crop rotation will replace older trees with younger trees for more water absorption. There is an effort to move contaminated soil from three contaminated units close to the ORWBG into the ORWBG for a large dollar savings. The units are Warner Pond, HRB, and HP52. They amount to 32,115 cu. yds. of material and 58.4 Ci. It is expected the Proposed Plan will be available in November or December. There will be an interim action to fill the Solvent Tanks with grout this summer. There was a presentation on the status of two-acre bamboo cover. The final sections of the draft Final Report were reviewed as well as the path forward.
6/14/01	Aiken Federal Building	Comments received during the technical accuracy review of the Final Report were discussed. Comments were received from BSRI, WSRC, several members of the ER Committee and FG. EPA, SCDHEC and DOE did not respond. Recommendation issues were discussed as well as distribution of the Final Report and path forward.

Appendix C.

Final Report to Citizen Advisory Board Concerning Corrective Measures to Remediate the old Radioactive Waste Burial Ground

By

Independent Scientific Peer Review Team

August 2000

FINAL REPORT TO CITIZEN ADVISORY BOARD CONCERNING CORRECTIVE MEASURES TO REMEDIATE THE OLD RADIOACTIVE WASTE BURIAL GROUND

BY

INDEPENDENT SCIENTIFIC PEER REVIEW TEAM
Dr. John A. Auxier, Consultant
Dr. Randall Charbeneau, Professor, University of Texas at Austin
Dr. Nolan E. Hertel, Professor, Georgia Tech
Dr. Ratib A. Karam, Professor Emeritus, Georgia Tech, Principal Investigator
Dr. Michael T. Ryan, Associate Professor, Medical University of South Carolina
Dr. F. Ward Whicker, Professor, Colorado State University

Task Order No. GA0050 (KE05243-O)
August, 2000
(modified 10-10-00)

For questions/comments, contact:
Dr. Ratib A. Karam
ERDA
900 Atlantic Drive
Atlanta, GA 30332-0425
(404)894-3620
(404)894-9326 (FAX)
ratib.karam@nnrc.gatech.edu

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Executive Summary

On December 1, 1999, the Education, Research and Development Association of Georgia Universities (ERDA) signed a contract with the Westinghouse Savannah River Company (WSRC) to provide an independent scientific peer review (ISPR) of the human health consequences to individuals at several locations in Four Mile Branch and the Savannah River. Specifically two areas of interest were requested: (1) provide an estimate of surface water contamination for Constituents of Interest (COIs) from waste buried in the Old Radioactive Waste Burial Ground (ORWBG); and (2) determine health risk at various locations impacted by the surface contamination originating in ORWBG and flowing to Four Mile Branch (FMB).

Initially a Gaussian-source plume model was employed. This model was found inappropriate because the burial ground size was large and the seep line was relatively too close to the ORWBG.

The model that was finally adopted comprised a burial ground that had a length of 1,000 feet, a width of 3,500 feet, and a depth of 16 feet. The burial ground was situated over a vadose zone 35 feet thick. Below the vadose zone was a 22 foot-thick aquifer flowing at 160 feet per year. The model accounts for aquifer transport including advection, dispersion, solute partitioning to aquifer solids and liquids, and radioactive decay. The model calculates a vertically averaged concentration over the plume thickness as a function of time and location. In essence the problem was reduced to a horizontal-plane-source with the contamination being carried in the direction of the aquifer flow.

The model was calibrated with the amount of tritium measured each year that is transported to FMB from ORWBG dating back to 1968. The calculated results and measurements are in good agreement and indicate that peak release of tritium to FMB from ORWBG occurred in 1989. The calculated release of tritium to FMB show that a person during the year 2000 drinking 2.2 liters per day from water collected at the seep line which feeds FMB would receive a committed effective dose equivalent (CEDE)[1] of 51 mrem per year. The dose rate at sampling point FM-6 for the same year drops to 3.4 mrem/year. This drop in dose rate is due to only the increase in the volume of water that flows through FMB at point FM-6. Distance from the seep line to FM-6 is not responsible for the drop. The same calculations indicate that by 2007 the concentration of tritium at the seep line would go below the EPA limit for drinking water of 20,000 pCi/L.

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[1] The committed effective dose equivalent (CEDE) may be defined as the life-time effective dose impacted to all tissues and organs from an intake of a known amount of radioactive material.

The same model as calibrated for tritium was used for the other fifteen COIs which were deemed of importance in the CMS/FS study. The results show that the highest dose rate at the seep line comes from I^{129} (9.41 mrem) and that would occur two hundred years after 1952 (2152).

Neptunium-237 and C^{14} produced yearly dose rates of 6.18 and 4.96 mrem/year respectively at peak concentration. Of course, peak concentrations occur at different times for different nuclides. For example for Np^{237} and for C^{14} peak concentration occur 800 years after 1952 (2752). For plutonium peak concentration occurs some 80,000 years after 1952 and for Tc^{99} peak concentration occurs in 2003.

For non-radioactive COIs such as Cd, Hg, Pb and VOCs, the calculated values are relatively close to but all remained below EPA limits. For example, the EPA limit for mercury is 2 µg/L. The calculated concentration at the seep line is 1.4 µg/L. For VOCs the EPA limit is 0.1 mg/L. The calculated concentration is 0.093 mg/L. The EPA limit/calculated values for Cd and Pb are 5.0/0.33 µg/L and 15.0/0.63 µg/L respectively. Even though ISPR members believe that the calculations yielded conservative values, i.e. calculated values should be higher than measured values, nevertheless to be more confident in the validity of the model to predict accurate results, it would be necessary to calibrate the model for each nuclide.

A key parameter in the model is the partition coefficient, K_d[2]. Calculated results are highly dependent on the value K_d used for each nuclide. One straightforward method for calibration is to use measured values of the pollutants at specific locations with known flow rates as a function of time, as was done for tritium. Calibration for each nuclide would generate confidence in the results obtained and would render decision-making on environmental remediation much easier with perhaps significant savings in cost.

Finally based on the analyses detailed in this report, the ISPR members unanimously make the following recommendations:

(1) Tritium is the major contributor to health risk at the seep line of FMB, contributing 51 mrem for drinking one's entire water needs for a whole year taken from the seep line in year 2000. However, since the seep line is within government-controlled access areas and since in 5-10 years[3] the tritium concentration at the seep line is expected to decline to levels below EPA

[2] The partition coefficient, K_d, is defined as the ratio of the waste in solid form in units of Ci/Kg to the concentration of the waste in the liquid in units of Ci/L.
[3] The range of 5-10 years is included to allow for possible error in the calculations. The calculated date when the concentration of tritium dips below 20,000 pCi/year is 2007.

requirements (i.e. < 20,000 pCi/L), no corrective action of any kind to remediate the tritium concentration in FMB is recommended.

(2) In order to extend the recommendation concerning corrective action(s) to the other COIs, calibration of the model using measured concentration of each COI at known flow rates at specific points along FMB must be undertaken immediately. No measured data of COI nuclides, other than H^3, was provided to the ISPR team for analysis and calibration. Additionally measured concentrations of constituents must be evaluated for consistency and place of origin. Remedial action may or may not be needed for COIs other than tritium. However, without the additional calibration, the ISPR team is not able to give a definite recommendation on the other COIs.

Introduction

On December 1, 1999, the Education, Research & Development Association of Georgia Universities (ERDA) signed a contract with the Westinghouse Savannah River Company to provide an independent scientific peer review of the human health consequences to individuals at several locations in Four Mile Branch and the Savannah River. Specifically two areas of interest were requested: (1) provide a simplified estimate of surface water stream concentration for constituents of interest (COIs) from waste buried in the Old Radioactive Waste Burial Ground (ORWBG); and (2) use the concentrations to determine the potential incremental health risk to various receptors at several locations down the path of surface water flow, that include several locations in the Savannah River.

The Old Radioactive Waste Burial Ground (ORWBG) at the Savannah River Site (SRS) consists of three areas that operated from 1952 through 1974 (see map in Appendix). The original, central portion is approximately 36 acres in size and operated from 1952 through the early 1960's. The east portion is 15 acres in size and received waste from 1961-72, while the west portion is 26 acres in size and operated from 1961-74. Tritium disposal in the west portion occurred between 1961 and 1972.

Tritium disposal occurred in three major waste forms: bulk waste, spent melts and reactive beds. Tritium in bulk waste (i.e. job control waste, waste oils and mercury, and used equipment and components) is readily leachable while tritium in spent melts (i.e. lithium-aluminum alloy that was heated to remove most of the tritium) is not readily released to infiltrating water. Reactive beds such as magnesium and other beds were used to convert tritiated water to elemental tritium and to concentrate the tritium. Most of the spent melts were disposed of in the east landfill, while tritium bulk waste was primarily disposed of in the west landfill. (Source: WSRC-RP-97, Rev. 1.1, October, 1998)

In addition to tritium the other radioactive Constituents of Interest (COIs) included in this report are cesium-137 (Cs^{137}), plutonium-238 (Pu^{238}), plutonium-239 (Pu^{239}), strontium-90 (Sr^{90}), uranium-235 (U^{235}), uranium-238 (U^{238}), carbon-14 (C^{14}), cobalt-60 (Co^{60}), technetium-99 (Tc^{99}), Iodine-129 (I^{129}), and neptunium-237 (Np^{237}). Non-radioactive COIs included are cadmium (Cd), mercury (Hg), lead (Pb), and VOCs.

The selected locations of study that were specified in the scope of work were (1) the seep line of Four-Mile Branch, (2) Road C, (3) FM-6, (4) across from the Vogle Plant, (5) the highway 301 bridge, and (6) RM-60.9, approximately 20-30 miles upstream from Beaufort-Jasper. During the study, it was discovered that no data are available for the area across from the Vogle plant.

The Education, Research & Development Association of Georgia Universities (ERDA) is pleased to submit this final report prepared by the Independent Scientific Peer Review Panel describing a mathematical model of transport of pollutants from the Old Radioactive Waste Burial Ground to the Four Mile Branch Creek. The model was developed by one of the panel members (Dr. Randall J. Charbeneau) and was used to calculate the concentrations of constituents of interest (COIs) in groundwater beneath and downgradient of the Burial Ground, along the seeps to Four Mile Creek (FMC), and in the FMC water. The calculations are based on an inventory of COIs that was delivered to the ORWBG during its 22-year period of operations (1952–1974). Based on the constituent inventory that is present, the model calculates the release to the vadose zone and subsequent transport to groundwater flowing beneath the ORWBG.

In an earlier analysis we used a Gaussian-source plume model to describe aquifer transport, including advection, dispersion, solute partitioning to aquifer solids, dilution and radioactive decay. Calibration of the Gaussian-source plume model to this data lead to unrealistic parameter estimates that are believed to be associated with representation of the source geometry. The earlier model assumed that the source may be represented by a linear boundary of finite width transverse to the direction of flow. It is difficult to place this boundary at a fixed distance from FMC, which also must be represented as a linear boundary. The primary difficulty is that the length of the source (the landfill) in the direction of groundwater flow is significant compared to the distance from the source to the receptor (FMC and its drainage seeps).

Subsequent to that analysis we received data of measured tritium mass flux to FMC (1). An alternative model was formulated and developed that incorporates the finite size of the landfill both in length and width. This is a Horizontal-Plane-Source model (HPS) that describes aquifer transport, including advection, dispersion, solute partitioning to aquifer solids, and radioactive decay. Creek water concentration is calculated by dilution of the mass flux to the creek with the creek discharge. Dose rate calculations to a person drinking 2.2 liters per day from Four Mile Creek for a whole year are included for all the radioactive COIs that make it through the vadose zone.

A sketch of the geometrical relationship of the Old Radioactive Waste Burial Ground (henceforth referred to as burial facility or simply facility) to the vadose zone and the aquifer beneath it is shown in Figure 1 (taken from reference 2). The Burial Facility is shown occupying the volume of a rectangular box. Leachate from the facility moves downward through the vadose zone and enters the aquifer within a rectangular area. The contaminant penetrates the aquifer and is carried down gradient towards an exposure location, which is shown as a well in this figure. In the model used herein, the contaminant plume is captured by FMC and mixes with the creek water. Dose calculations are based on the concentrations at the seep line and in creek water. The following sections describe the inventory model, the model for leachate generation and vadose zone transport, the Horizontal-Plane-source plume model for aquifer transport, and the mixing model that provides estimates of COI concentrations in the creek.

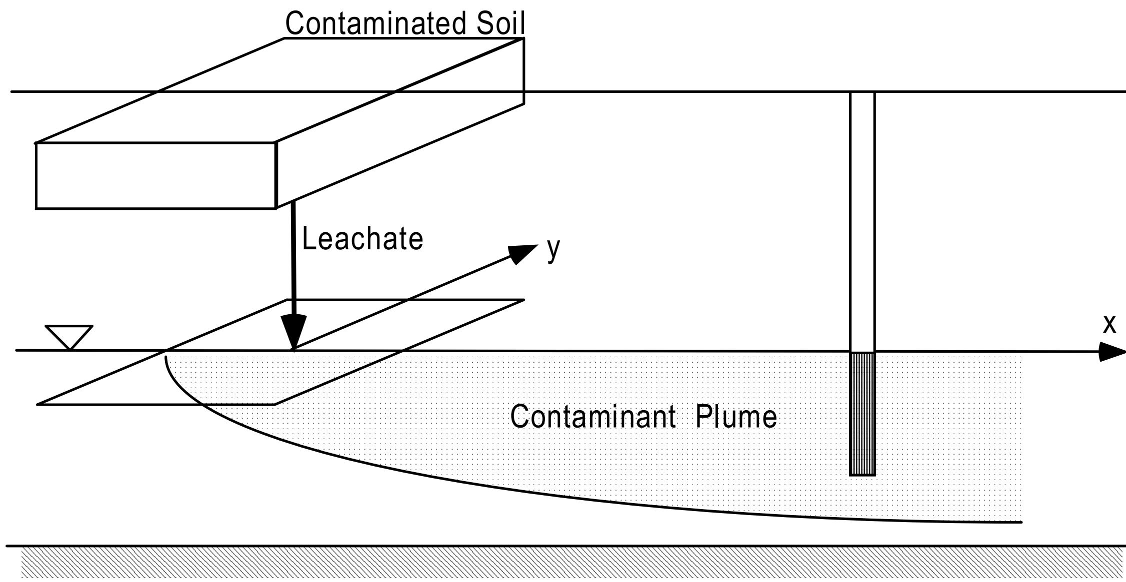

Figure 1. Groundwater Exposures from the ORWBG

<u>Model for the COI Inventory within the ORWBG</u>

Historical records provide only very general data that may be used to estimate the amounts of the various COIs that were disposed of within the ORWBG. These data consist of estimates of the total inventory I_o (Ci) that was delivered to the facility during its period of operation Δt_O (22 years). For this analysis it is assumed that the inventory delivery rate $\dot{I}$ (Ci/yr) increased linearly through time during a ramping period of duration Δt_R, and then remained constant at a rate $\dot{I}_m$ for the remaining duration of operations $\Delta t_R < t < \Delta t_O$. This assumed delivery-rate schedule is shown in Figure 2.

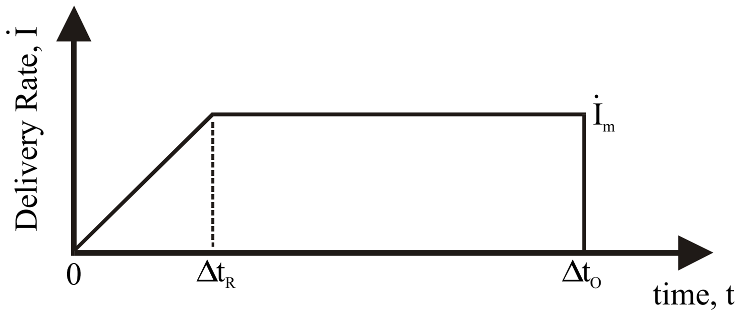

Figure 2. Assumed Inventory Delivery-Rate Schedule

Balance considerations show that $I_o = \frac{1}{2}\dot{I}_m \Delta t_R + \dot{I}_m(\Delta t_O - \Delta t_R)$, and thus

$$\dot{I}_m = \frac{I_o}{\Delta t_O - \frac{1}{2}\Delta t_R} \tag{1}$$

Equation (1) relates the maximum COI disposal rate to the total delivered inventory, the duration of facility operation, and the duration of the ramping period.

During the period of operation (1952-74) and following post-closure period, the nuclide inventory is lost from the ORWBG through radioactive decay and leaching. The COI leaching model is based on movement of water that infiltrates through the facility at a rate q_f (ft/yr) contacting a fraction f_L of the nuclide inventory, and transporting the COI from the facility as leachate. The facility waste has a volumetric water content θ_{waste} and bulk density ρ_{waste} (kg/L), and the COI partitions between the waste solids and water with partition coefficient K_d^w (L/kg). L_{waste} is the vertical thickness of the disposed waste in the Burial Ground. The COI release rate $\dot{m}_f$ (Ci/yr) as leachate from the ORWBG that has an inventory I(t) in curies at time t is calculated from

$$\dot{m}_f(t) = \lambda_L \; I(t) \tag{2}$$

In equation (2), the leach-rate constant λ_L is calculated from

$$\lambda_L = \frac{q_f \; f_L}{\left(\theta_{waste} + \rho_{waste} K_d^{\,w}\right) L_{waste}} \tag{3}$$

In equation (3), the variable q_f is the average annual infiltration rate, which is the average annual rainfall less subtractions that include average runoff and evapotranspiration. The factor f_L is dimensionless and accounts for the fraction of waste in contact with water and hence accounts for the mass transfer from waste to percolating water. For simplicity and because other data are not available, a value $f_L = 1.0$ is assumed for all simulations.

The partition coefficient K_d is defined as the ration of the concentration of the waste in solid form in units of Ci/Kg to the concentration of the waste in the liquid in units of Ci/L.

$$K_d \quad = \quad \frac{C_{waste}\ (Ci\,/\,Kg)}{C_{waste}\ (Ci\,/\,L)}$$

The COI inventory at time t, I(t), is found by solving the following series of continuity equations that relate the change in inventory to its delivery rate and its loss rate due to radioactive decay and leaching. During the period of increasing delivery rate (ramping period), $0 < t < \Delta t_R$, the balance equation is

$$\frac{dI}{dt} = \dot{I}_m \frac{t}{\Delta t_R} - \lambda_f I \quad ; \quad I(0) = 0 \tag{4}$$

In equation (4), the facility loss-rate λ_f includes losses from radioactive decay and leaching, $\lambda_f = \lambda_D + \lambda_L$, where λ_D is the isotopic decay constant. Solving equation (4) gives the inventory

$$I(t) = \frac{\dot{I}_m}{\Delta t_R\, \lambda_f^{\,2}}\left[\lambda_f\, t - \left(1 - e^{-\lambda_f t}\right)\right] \quad ; \quad 0 \le t \le \Delta t_R \tag{5}$$

During the subsequent period of operation with a constant delivery rate, $\Delta t_R < t < \Delta t_O$, the inventory balance equation is

$$\frac{dI}{dt} = \dot{I}_m - \lambda_f I \quad ; \quad I(\Delta t_R) = \frac{\dot{I}_m}{\lambda_f} - \frac{\dot{I}_m}{\Delta t_R\, \lambda_f^{\,2}}\left(1 - e^{-\lambda_f \Delta t_R}\right) \tag{6}$$

Solving equation (6) gives

$$I(t) = \frac{\dot{I}_m}{\lambda_f} - \frac{\dot{I}_m}{\Delta t_R \, \lambda_f^{\,2}} \left(e^{\lambda_f \Delta t_R} - 1\right) e^{-\lambda_f t} \quad ; \quad \Delta t_R \le t \le \Delta t_O \tag{7}$$

The maximum inventory I_{max} occurs at $t = \Delta t_O$.

$$I_{max} = \frac{\dot{I}_m}{\lambda_f} - \frac{\dot{I}_m}{\Delta t_R \, \lambda_f^{\,2}} \left(e^{\lambda_f \Delta t_R} - 1\right) e^{-\lambda_f \Delta t_O} \tag{8}$$

Following closure of the facility, there is no inventory delivery rate, and the inventory decreases due to both leaching and decay, resulting in the inventory model

$$I(t) = I_{max} \; e^{-\lambda_f \,(t - \Delta t_O)} \quad ; \quad t \ge \Delta t_O \tag{9}$$

Equations (5), (7) and (9) provide the model for determining the COI inventory through time.

<u>Leachate Generation and Vadose Zone Transport</u>

The previous section presents a mathematical model for predicting the ORWBG facility inventory of a COI as a function of time. Estimates of groundwater and creek concentrations of various COIs require calculation of leachate generation from the facility and vadose zone transport to groundwater flowing beneath the facility. Equations (2) and (3) provide the model for leachate generation. According to equation (2) the leachate generation rate (Ci/yr) is proportional to the facility inventory. The leach-rate constant is determined by the values of the variables in Eq(3) that characterize the facility.

A simple (and appropriate) model for vadose zone transport is to assume advection transport based on the facility infiltration rate q_f, the vadose zone volumetric water content θ_{vz}, and the thickness of the vadose zone L_{vz}. The nuclide travel time through the vadose zone is calculated from (see reference 2, Equation 9.6.11)

$$\Delta t_{vz} = \frac{\left(\theta_{vz} + \rho_b K_d\right) L_{vz}}{q_f} \tag{10}$$

In equation (10), ρ_b is the soil bulk density and K_d is the soil-water partition coefficient for the nuclide in the vadose zone.

The leachate supply-rate to the water table (Ci/yr) is calculated from

$$\dot{m}_{wt}(t) = \lambda_L \; I(t - \Delta t_{vz})\, e^{-\lambda_D \Delta t_{vz}} \tag{11}$$

Comparison of equations (2) and (11) show that the leachate supply-rate to the water table is equal to the leachate generation rate at an earlier time, multiplied by a factor that accounts for losses due to decay during the time of vadose zone transport.

Horizontal-Plane-Source Plume Groundwater Transport Model

The Horizontal-plane-source (HPS) plume model allows for representation of one-dimensional flow, longitudinal and transverse horizontal and vertical dispersion, linear sorption, isotopic radioactive decay, finite-size source zone, and a time-variable source release. Figure 1 shows the geometry of the model used. The model calculates the vertically averaged concentration c(x,y,t) at any location and time. The model is setup with the direction of flow corresponding to the x-axis. The aquifer transport equation may be developed using mass conservation principles (see reference 2), and is given by

$$R \frac{\partial c}{\partial t} + v \frac{\partial c}{\partial x} + \lambda_D \, c = D_{xx} \frac{\partial^2 c}{\partial x^2} + D_{yy} \frac{\partial^2 c}{\partial y^2} \tag{12}$$

In equation (12), R is the retardation factor ($R = 1 + \rho_b K_d / n$, where n is the aquifer porosity), which may be interpreted as the ratio of the velocity of groundwater to the average solute velocity. The parameter v is the aquifer seepage velocity that is assumed to occur in the x-direction. The parameters D_{xx} and D_{yy} are the longitudinal and transverse dispersion coefficients, and are equal to the product of the longitudinal and transverse dispersivities and the seepage velocity, respectively (i.e., $D_{xx} = a_L$ v; $D_{yy} = a_T$ v, where a_L and a_T are the longitudinal and transverse dispersivity). The concentration c(x,y,t) in equation (12) represents the vertically average concentration over the aquifer thickness H.

For this model the source is represented by an initial value problem where a contaminant of unit mass is initially uniformly distributed within a box of length L in the direction of groundwater flow, width W transverse to this direction, and thickness H. This corresponds to an instantaneous release or "spill" of unit mass. The mathematical solution for this spill model is given by (see reference 2, Section 8.7.6)

$$c_s(x,y,t) = \frac{1}{4nRHLW}\left\{ \mathrm{erf}\left(\frac{x - v't + L/2}{\sqrt{4D_{xx}{'}t}} \right) - \mathrm{erf}\left(\frac{x - v't - L/2}{\sqrt{4D_{xx}{'}t}} \right) \right\} \bullet$$
$$\left\{ \mathrm{erf}\left(\frac{y + W/2}{\sqrt{4D_{yy}{'}t}} \right) - \mathrm{erf}\left(\frac{y - W/2}{4D_{yy}{'}t} \right) \right\} \bullet e^{-\lambda_D t} \tag{13}$$

In equation (13), v' is the retarded seepage velocity ($v' = v/R$) and D_{ii}' is the retarded dispersion coefficient.

Equation (13) gives the concentration at location (x,y) and time t due to a release of unit mass uniformly over a rectangle of length L and width W centered at the origin (x=0,y=0) at time zero. The solution for the contaminant plume corresponding to the time-variable release rate from the ORWBG given by Equation (11) is found through convolution of Equations (11) and (13):

$$c_p(x,y,t) = \int_0^t \dot{m}_{wt}(\tau) c_s(x,y,t-\tau)\, d\tau \tag{14}$$

<u>Flux to Four Mile Creek and Creek Concentration</u>

For this model representation, the Four Mile Creek is treated as a linear boundary at a distance $x = X_c$ from the middle of the ORWBG. It is assumed that all of the nuclide activity (and COI mass) that passes this boundary enters the creek system. This transport rate (Ci/yr) is calculated by integrating the advection flux crossing the linear boundary representing the creek. Due to symmetry this is given by

$$\dot{m}_c(t) = 2\, n\, v\, H \int_0^{y_{max}} c_p(X_c, y, t)\, dy \tag{15}$$

If Q_c is the average discharge (L^3/year) in Four Mile Creek, then the creek water concentration immediately downstream of the region of seepage from the ORWBG is calculated from

$$c_c(t) = \frac{\dot{m}_c(t)}{Q_c} \tag{16}$$

Equations (1) through (16) provide the mathematical model for estimating the concentrations and mass flux of COIs in the aquifer beneath the ORWBG and in FMC.

Model Implementation

The theoretical model was implemented through an Excel workbook. The convolution integral of Equation (14) and the quadrature of Equation (15) are evaluated using a module that is written to implement Simpson's rule with user selected convergence criteria. In particular, since Equation (15) utilizes the solution from Equation (14), calculation of the mass flux to FMC and the corresponding creek concentration requires a double quadrature using Simpson's rule.

The Excel solution workbook has one worksheet requiring user-supplied data (see Figure 3). The required data are highlighted in gray (blue on the computer worksheet). The data entry occurs in blocks. The first block requires *inventory* and *nuclide decay* data (the total delivered inventory I_o, the duration of inventory delivery rate ramping Δt_R, duration of facility operation Δt_O, and the nuclide half-life $T_{1/2}$).

The second block requires *nuclide leaching* parameters corresponding to the facility infiltration rate q_f, leaching factor f_L, facility waste water content θ_{waste} and bulk density ρ_{waste}, nuclide-waste soil-water partition coefficient K_d^w, and waste thickness L_{waste}. Because other information is not available, the value of K_d^w was assumed to be the same as the aquifer K_d value; that is, no credit is taken for an advanced waste form. This assumption is arbitrary and may be adjusted as better knowledge of the waste form is gained.

The third block (*Vadose Zone*) requires the vadose zone thickness beneath the burial grounds L_{vz} and the water content in the vadose zone θ_{vz}. This data is used with the inventory and leaching data to calculate the nuclide flux to the water table following opening of the ORWBG (1952).

The fourth block (*Aquifer Parameters*) requires groundwater transport parameters including the aquifer Darcy velocity, q_x, the porosity n, the longitudinal and transverse dispersivities a_L and a_T, the length L and width W of the ORWBG source zone, the plume thickness H, and the aquifer bulk density ρ_b and distribution coefficient K_d. The aquifer seepage velocity v is calculated from values of q_x and n.

The remaining data include the *Creek Discharge* Q_c and the quadrature *Integral Convergence Criteria*. The parameters ε_1 and ε_2 determine the convergence for Simpson's algorithm for Equations (14) and (15), respectively.

Delivered Inventory and Nuclide Decay

I_o (Ci)	**1.48E+03**	λ_D (yr^{-1})	0.0000
Δt_R (yr)	**0.05**	I_m (Ci/yr)	76
Δt_O (yr)	**22**		
$T_{1/2}$ (yr)	**2.44E+04**		

Summary

Total Flux to Water Table (Ci) =	**5.39E+02**
Total Flux to Creek (Ci) =	**1.07E+02**
Maximum Flux to Water Table (Ci/yr) =	**6.09E-02**
Maximum Flux to Creek (Ci/yr) =	**2.41E-03**
Maximum Creek Concentration (pCi/L) =	**3.1E-01**

Leaching

q_f (ft/yr)	**1.25**	λ_L (yr^{-1})	8.875E-05
f_L	**1.00**	I_{max} (Ci)	1473
θ_{waste}	**0.25**		
ρ_{waste} (kg/L)	**1.6**		
K_d^w (L/kg)	**550**		
L_{waste} (ft)	**16**		

Vadose Zone

L_{vz} (ft)	**35**	Δt_{vz} (yr)	24645.6
θ_{vz}	**0.2**		

Aquifer Parameters

q_x (ft/yr)	**40**	R	3521
n	**0.25**	D_{xx}' (ft^2/yr)	6.1346208
a_L (ft)	**135**	D_{yy}' (ft^2/yr)	1
a_T (ft)	**17**	v_x' (ft/yr)	0.045
L (ft)	**1000**	c_o/M (ft^{-3})	3.69E-12
W (ft)	**3500**		
H (ft)	**22**		
ρ_b (kg/L)	**1.6**		
K_d (L/kg)	**550**		

Creek Discharge

Q_c (m^3/yr)	**7.80E+06**

Integral Convergence Criteria

ε_1	**0.01**	**Local Concentration**
ε_2	**0.1**	**Creek Flux**

Figure 3. Data Entry Form for Model

Four separate worksheets show the results from the model calculations. The *Inventory* sheet, which follows the *Data* worksheet, shows the landfill nuclide inventory and mass flux to the water table through a user-specified time interval. The *Profile* worksheet shows the plume concentration distribution along a user-specified range of plume length (x_{min} to x_{max}) at a selected transverse location (y-coordinate) and time. The *XSection* worksheet shows the concentration distribution across the plume cross-section at a given user-specified x-location and time for the range $-y_{max} < y < y_{max}$. This worksheet is used to verify that the y-range in the creek-flux calculation is appropriate. The last worksheet, *Flux*, presents the calculations for the constituent flux to the creek and the resulting creek concentration, where the user selects the distance to the linear-creek-boundary X_c and time range.

For the non-radioactive COIs, i.e. cadmium, mercury, lead, and VOCS, the input is in kilograms quantities rather than curies. Consequently the output unit is also kg instead of what is labeled as curies. The concentration to the water table and the creek should be in units of pkg/L, or ng/L (nanograms per liter) instead of pCi/L.

Calibration of Tritium in FMC

A. Assumptions

For purposes of model calibration, an assumption was made that the west landfill is primarily responsible for tritium leachate to Four Mile Branch Creek (FMC). The measured mass flux (Ci/yr) in the FMC was used to calibrate the model. Physical parameters, primarily the source term, were adjusted in order to produce the observed timing of the release and mass flux to the creek. Only the west landfill was modeled over the twelve-year period 1961-72. Approximately 2M Ci of tritium were disposed of prior to this time period (1952-60), and not all of the tritium that was disposed of during this period is in a leachable form. (Source: WSRC-RP-97-00127, Rev. 1.1, PE-6, Oct., 1998) The effective distance from the center of the west landfill to the nearest point of FMC is assumed to be 2600 ft, and the burial ground is assumed to have a length L = 1100 ft. in the direction of groundwater flow towards FMC, a width W = 1000 ft., and a depth of 16 ft.

B. Calculations vs. Measured Results

Figure 4 shows the measured tritium flux to FMC along with the calculated results. The solid line represents calculated values. The diamonds represent measured data, taken from reference 1. The calculation gives a flux of 6800 Ci/yr in 1990, which compares with a measured tritium flux to FMC of 6420 Ci/yr in 1991. The measured and calculated fluxes in 1998 are 3490 and 3600

Ci/yr, respectively. With an average creek discharge of 7,800,000 m^3/yr at a point below the seep line, this corresponds to a calculated creek concentration of 430,000 pCi/L.

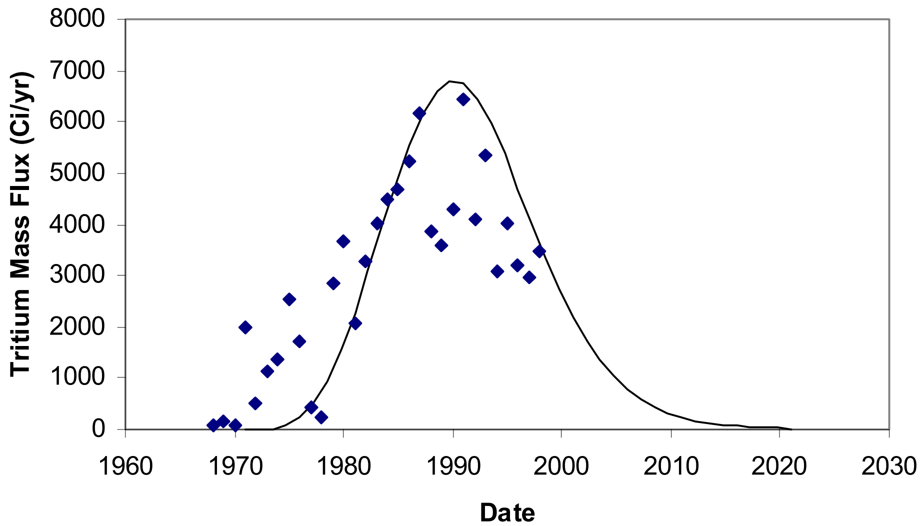

Figure 4. Comparison of Observed Data and Model Simulation For Tritium in Four Mile Branch Creek

Measured flow rates and tritium concentration at FM-6 for 1997, 1998 and 1999 were as follows:

Table 1. Measured Flow Rates and Concentration at FM-6 for 1997 – 1999		
	Flow Rate m^3/year	Concentration pCi/L
FM-6 (1997)	2.28×10^7	2.16×10^5
FM-6 (1998)	3.76×10^7	1.86×10^5
FM-6 (1999)	1.81×10^7	1.94×10^5
Three Year Average	2.62×10^7	1.98×10^5
Source: Data supplied by Peter Fledderman of WSRC. ISPR members are grateful for Mr. Fledderman's assistance.		

$$\text{Aver Ci/year} = \frac{2.62\times10^{7}\ \text{meter}^{3}}{\text{year}} \quad \times \quad \frac{1000\ \text{L}}{\text{m}^{3}} \quad \times \quad 2.02 \quad \times \quad 10^{5}\ \frac{\text{pCi}}{\text{L}}$$

$$= 5.187\times10^{15}\frac{\text{pCi}}{\text{year}}$$

or 5,187 Ci/year

According to data supplied by Lee Poe (CAB) the fraction of total tritium that reaches FM-6 that originated at ORWBG is 60% of the total. Consequently ORWBG contribution to the total flux at FM-6 is

$$0.6 \quad \times \quad 5{,}187\,\frac{\text{Ci}}{\text{year}} \quad = \quad 3{,}112\,\frac{\text{Ci}}{\text{year}}.$$

This number should be compared with a calculated value of 2,710 Ci/year for 1999.

The basic input data that were used in the calculations shown in Figure 4 are presented in Table 2. It is assumed that the inventory was delivered at a uniform rate over the 12-year period (1961-72, inclusive) and Δt_R is set to a small number (0.05 yrs). Within the vadose zone and aquifer, tritium is assumed to be present as tritiated water, and its partition function is set to zero ($K_d = K_d^{w} = 0.0$). The aquifer volume flux (Darcy velocity) and effective porosity result in a seepage velocity (average linear velocity of groundwater flow) of 160 ft/yr. Dispersion parameters are estimated using average values from the formulation presented in background documents for EPA's <u>Composite Model for Landfills</u> (reference 2, Eq. 8.5.9). Based on a distance of 2100 ft from the down gradient edge of the landfill to the receptor, the estimated dispersivities are a_L = 135 ft, a_T = 17 ft, and a_v = 0.85 ft. Furthermore, at the receptor the aquifer is assumed to be vertically mixed (see Eq. 8.7.33c, reference 2). A two-dimensional model formulation was used, as presented in Eq. 13.

The data in Table 2 determine the timing of the tritium flux to FMC. The inventory that is available for leaching is determined by adjusting the total delivered inventory, I_o, to match the peak observed flux to FMC, resulting in a tritium leaching-inventory delivered to the west burial ground of 475,000 Ci.

Table 2. Basic Data Used in Tritium Calibration Simulation

Operational Data	
Inventory delivery ramping time, Δt_R	0.05 years
ORWBG duration of operations, Δt_O	12 years
Leaching and Waste Data	
Facility infiltration rate, q_f	1.25 ft/yr
Leaching fraction, f_L	1.0
Volumetric water content, θ_{waste}	0.25
Bulk density, ρ_{waste}	1.6 kg/L
Thickness, L_{waste}	16 ft
Vadose Zone Data	
Thickness, L_{vz}	35 ft
Volumetric water content, θ_{vz}	0.20
Aquifer Data	
Darcy velocity, q_x	40 ft/yr
Effective Porosity, n	0.25
Longitudinal dispersivity, a_L	135 ft
Transverse dispersivity, a_T	17 ft
Plume thickness, H	22 ft
Bulk density, ρ_b	1.6 kg/L
Creek Data	
Distance from center of ORWBG, X_c	2600 ft
Discharge, Q_c	$7.8(10^6)$ m^3/yr

The tritium "leaching-inventory" for the west landfill of the ORWBG is shown in Figure 5. While 475,000 Ci are delivered over the 12-year period, the maximum inventory in year twelve is 106,000 Ci because of decay (tritium half-life = 12.4 years). At any time, the release rate from the facility is equal to the product of the inventory and the leach-rate constant (see Eq. 2).

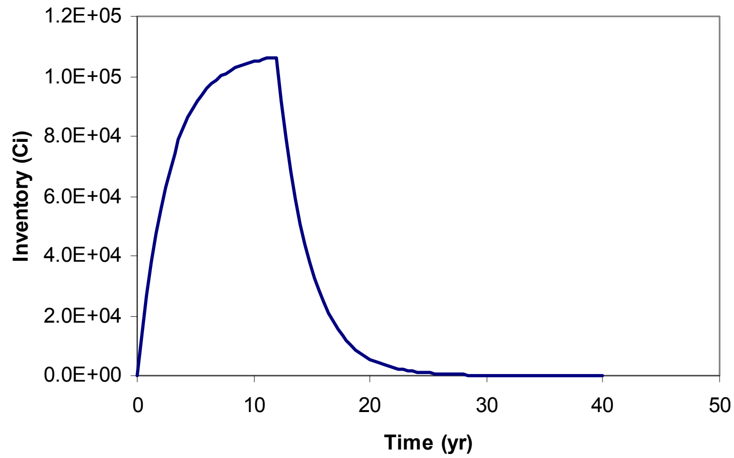

Figure 5. ORWBG Facility Inventory Estimates for Tritium (leaching inventory for the west landfill) beginning in 1961

The simulated tritium plume centerline concentration is shown in Figure 6 for the year 1998.

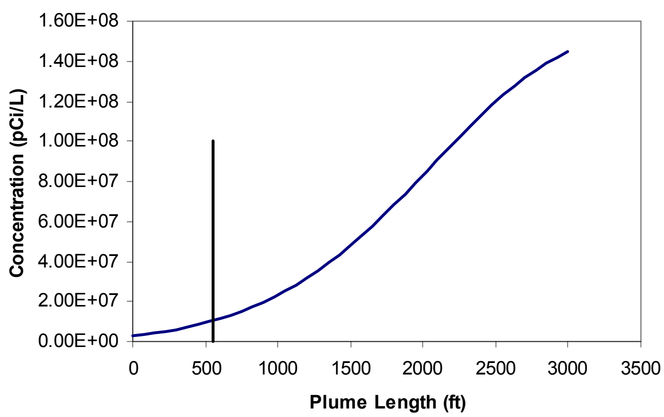

Figure 6.
Prediction of the 1998 Tritium Concentration
along the Plume Centerline

The vertical line marks the downgradient edge of the landfill. The concentration beneath the landfill is approximately $3(10^6)$ pCi/L, while the concentration at a distance of 1500 ft from the landfill exceeds 10^8 pCi/L.

The tritium plume cross-section concentration along FMC (X_c = 2600 ft) is shown in Figure 7. The effective plume width is approximately 3000 ft (y_{max} = 1500 ft), and this value is used in calculating the creek flux using Eq. 15.

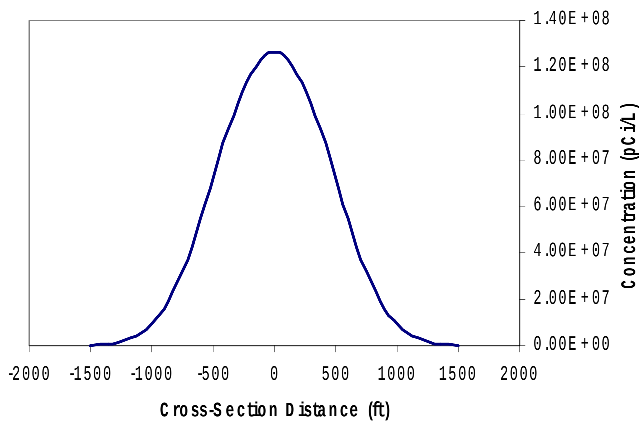

Figure 7. Predicted FMC Groundwater Seepage
Concentration for Tritium in 1998

Another set of input parameters for the calculation of tritium transport to Four Mile Branch from ORWBG were used for purposes of comparison with the somewhat arbitrary adjustment of the source inventory used above in order to obtain agreement with measured tritium concentration in FMB. This set of input parameters comprise a tritium source inventory of 3,014,457 curies, a ramping period of Δt_R = 5 years and Δt_O = 20 years (1952-1972) based on data found in WSRC-RP-98, Rev. March 1999. The length L and width W of the facility were 1,000 and 35,000 feet. All other parameters are the same as reported in Table 2, and as used for other COIs that are described below. With this calculation the maximum flux to FM was 35,800 Ci/year occurring in 1987. The tritium concentration at FM-6 for 1998 was 3.2 x 10^5 pCi/L. This value exceeds the value of 1.16 x 10^5 pCi/L measured during 1998 after adjustment for ORWBG contribution. Measured concentration at FM-6 includes sources originating at places other than ORWBG. In fact it was estimated that only 60% of the total at FM-6 originates at ORWBG.

A third set of calculations for tritium transport to FMB from ORWBG were performed under identical conditions as the first set except that the source inventory was increased to 1,000,000 curies. The justification for the increase to one million curies is as follows:

(1) The tritium plume in the water table seems to be limited to the southwest area of the burial ground (see WSRC-RP-97-00127, Rev. 1.1 Redline Oct. 1, 1998, Vol. 1., Fig. 23,

pp. 2-69). Note that no plume appears to flow from the center or the east side of ORWBG toward FMB.

(2) The history of the tritium disposal in ORWBG, as cited in WSRC-RP-97-00127 Rev. 1.1, Redline Oct. 1, 1998 Vol. II, p. E-4, indicate that 2 million curies of tritium were buried prior to 1960 primarily in the central portions of ORWBG. Beginning in 1961 and ending 1972 one more million curies were buried in the west portion of ORWBG.

Complete input data and output results for this set of calculations are appended. The maximum tritium concentration in FMB at a flow rate of 7.8 x 10^6 m^3/year is 1.80 x 10^6 pCi/L and occurs in 1988. Since the 10 year average flow rate at the seepline is 2.22 x 10^6 m^3/year. The corresponding maximum 1988 seepline concentration is

$$1.80 \text{ x } 10^6 \text{ pCI/L x } \frac{7.8 \text{ x } 10^6}{2.22 \text{ x } 10^6} \quad \text{or}$$

6.32 x 10^6 pCi/L. For the year 2000, the seepline concentration drops to 2.34 x 10^6 pCi/L and at FM-6, the concentration drops to 1.59 x 10^5 pCi/L. This compares with measured values of 1.94 x 10^5 pCi/L. However, the contribution from ORWBG to the measured value is 0.6 x 1.94 x 10^5 pCi/L or 1.16 x 10^5 pCi/L. Consequently the calculation using 1 million curies over predict the concentration of tritium at FM-6 by about 37%.

<u>Calculated Results for Other COIs</u>

Measured concentrations were not available to the ISPR team for calibration of solute transport for other Constituents of Interest (COIs). Thus the hydrogeologic parameters that were used in the calibration of the tritium flux to FMC, were used for other COIs as well. However, the entire ORWBG landfills were considered. The ORWBG length was reduced from 1100 ft. to 1000 ft. to account for the fact that ORWBG is not a rectangle. The width used was 3500 ft. Furthermore, the entire disposed inventory was assumed to be leachable, and unless other data were available, it was assumed that Δt_O = 22 years with a 5-year ramping period (Δt_R = 5 years).

The plume width along FMC is shown in Figure 8 for Pu-239 at a time of 70,000 years after 1952. This figure shows that a value y_{max} = 2600 ft may be used for the FMC mass flux calculation, and this is assumed for other nuclides as well.

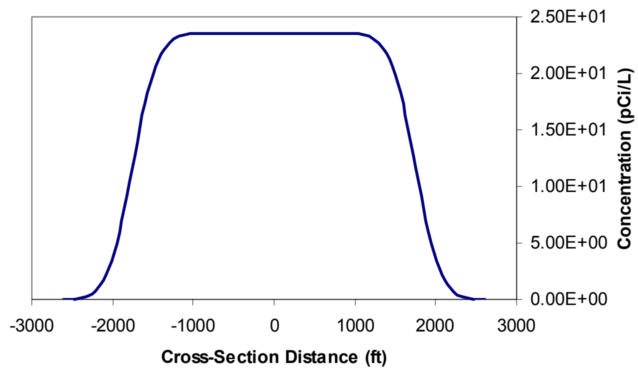

Figure 8. Predicted FMC Groundwater Seepage Concentration for Pu-239
With ORWBG Width of 3500 ft at Time 70,000 Years

The source inventory, half-life and distribution coefficients for the COIs are presented in Table 3, which also presents summary results for the calculation. K_d values are generally taken from Thibault et al. (4) for a sandy soil. For Pu^{238}, the travel time to the creek is very long, the same as for Pu^{239}, but because the half-life is relatively short (87 years) compared to 24360 years for Pu^{239}, no Pu^{238} gets to the creek. This result is governed primarily by the K_d value used, in this case 550 L/kg. Similar results are found for Cs^{137}, Sr^{90}, and Co^{60}. Furthermore, for plutonium and lead in FMC, the travel time exceeds 10,000 years.

VOCs are typically considered to be trichloroethylene (TCE). TCE and other chlorinated solvents are known to undergo biodegradation through metabolic pathways, where the enzymes that promote electron transfer are supplied during biodegradation of a primary substrate. Effective half-lives for cometabolism are uncertain, and a very conservative estimate of 100 years is assumed (5). The VOC partition coefficient is based on hydrophobic character and partitioning on soil organic carbon. A small soil organic carbon fraction of 0.1% was assumed.

Discussion

The peak concentration of tritium from the ORWBG in FMC was calculated to occur in 1989, which corresponds well with observed data since these data were used for calibration of the model. The peak H-3 concentration was about 870,000 pCi/L. The calculated current (year 1999) concentration at FM-6 is approximately 8.3×10^4 pCi/L, and the concentration from the

ORWBG should drop to 2,000 pCi/L by 2015. Note that 2,000 pCi/L is 10 times lower than the EPA standard of 20,000 pCi/L which is predicted to occur in 2007. Site land controls prevent exposure to tritium through ingestion by drinking water from FMC, and this will continue for the time period during which tritium presents somewhat of a risk through subsurface transport pathways. The model predicts that the time of peak concentration for both Tc-99 and VOCs occur in year 2003. VOCs have been measured in groundwater beyond the ORWBG. Information on concentrations of these COIs in FMC are not available at present. Potential exposures from these and other COIs are small and manageable, and as the following section shows, do not really present a risk.

Furthermore, the model for exposure to COIs from the ORWBG in FMC and beyond is conservative, i.e. calculated values are higher than measured values. Measured data also show that tritium has leached from the east landfill, and indeed the concentrations beneath the entire landfill are significant. However, tritium has not migrated from the central or east parts of ORWBG to FMC. It would appear that this landfill is located closer to, or on top of, the groundwater divide that is known to exist. However, the model assumes a high seepage velocity typical of the location of the west landfill for the entire ORWBG, resulting in a conservative (high) estimate of the exposure concentration in FMC.

Table 3. Input Parameters and Calculation Results

Constituents of Interest (COIs)	SOURCE INVENTORY (Curies)	HALF-LIFE (Years)	K_d (L/kg)	Transport to Water Table (Curies)	Transport to FMC (Curies)	Peak Conc. in FMC (pCi/L)	Time to Peak Conc. (Years)
H^3	475,000	12.4	0	295,000	114,000	872,000	29 *(1989)**
Cs^{137}	58,660	30	15	0.0011	--	--	1200
Pu^{238}	20,514	87.7	550	--	--	--	80,000
Pu^{239}	1,475	24,360	550	539	107	0.310	80,000
Sr^{90}	58,660	29.12	15	0.00069	--	--	1200
U^{235}	0.60	$7.1x10^8$	35	0.60	0.60	0.022	6000
U^{238}	14.8	$4.51x10^9$	35	14.8	14.8	0.53	6000
C^{14}	3,778	5,730	5	3,620	3,380	840	800
Co^{60}	1,960,400	5.27	10	--	--	--	600
Tc^{99}	12	213,000	0.1	12.0	12.0	53	52 *(2003)**
I^{129}	10.6	$1.57x10^7$	1	10.6	10.6	12	200
Np^{237}	1.99	$2.14x10^6$	5	1.99	1.99	0.49	800
Cd	1,591 kg	10^{10}	6	1590	1590	0.33 µg/L	1000
Hg	10,998 kg	10^{10}	10	11,000	11,000	1.4 µg/L	1700
Pb	50,000 kg	10^{10}	100	50,000	50,000	0.63 µg/L	16,000
VOCs	28,200 kg	100	0.1	25,400	20,700	93 µg/L	52 *(2003)**

Dose Calculations

Dr. Michael T. Ryan performed the dose calculations. Dose conversion factors in Sv/Bq, taken from EPAA-520/1-88-020, September 1988 are listed in Tables 3A and 3B for inhalation and ingestion respectively. The f_1 factor is the GI track uptake fraction.

The committed effective dose equivalent (CEDE) calculation for tritium based on ingestion of 2.2 liters of water for 365 days at various locations in FMB and the Savannah River are listed in Table 4 for the year 2000. The committed effective dose equivalent is defined as the sum, over all impacted tissues and organs, of the product of the committed dose equivalent and a weighting factor that incorporates the sensitivity of the tissue/organ into the body dose determination. The committed dose equivalent is defined as the dose equivalent to organs or tissues that will be received from an intake of radioactive material by an individual during a 50-year period following the intake. According to our calculation the maximum possible concentration in FMB occurred in 1989. Consequently, the calculated values in Table 4 are for the year 2000. The dose rate at the seep line is 51 mrem per year. The dose rate at FM-6 drops to 3.4 mrem/year. The dose rate at highway 301 Bridge drops to 0.01 mrem/year and at station RM-60.9 (some 20-30 miles upriver from Jasper-Beaufort is 0.009 mrem/year. It is noted that the values in Table 4 drop further by a factor of 40 for the year 2015.

The decrease in dose rates from the seep line to RM-60.9 and all the points in between is due to dilution of the tritium concentration caused by the increase in the volumetric water flow rates. No tritium is assumed to be lost along the way.

Dose rate standards are as follows:

- from all pathways = 100 mrem/year
- air pathways = 10 mrem/year
- drinking water pathways = 4 mrem/year

Natural background dose rates from all sources is equal to 300 mrem.

Other COIs CEDE calculations are listed in Table 5 for the same locations listed in Table 4 and as stipulated in the Scope of Work. Note that at no time does the yearly dose rate of any of the COIs exceed 10 mrem. The values listed in Table 5 are the maximum possible dose rates caused by drinking the water for a year and this maximum possible occurs at different times for each isotope.

Table 3A. Dose Conversion Factors and Other Dose Calculation Parameters for SRS ORWBG

limiting DCF's are in **bold**

Radionuclide	f1	Inhalation Class	Gonad	CEDE Inhalation SV/Bq					Remainder	Effective
				Breast	Lung	R Marrow	B Surface	Thyroid		
H-3	1.00E+00	Water Vapor	1.73E-11	1.73E-11	1.73E-11	1.73E-11	1.73E-11	1.73E-11	1.73E-11	1.73E-11
C-14	1.00E+00	Labeled Organic Compounds	5.64E-10	5.64E-10	5.64E-10	5.64E-10	5.64E-10	5.64E-10	5.64E-10	5.64E-10
C-14	1.00E+00	Carbon Monoxide	7.83E-13	7.83E-13	7.83E-13	7.83E-13	7.83E-13	7.83E-13	7.83E-13	7.83E-13
C-14	1.00E+00	Carbon Dioxide	6.36E-12	6.36E-12	6.36E-12	6.36E-12	6.36E-12	6.36E-12	6.36E-12	6.36E-12
Cl-36 (D)	1.00E+00	per associated element	5.04E-10	5.04E-10	1.33E-09	5.04E-10	5.04E-10	5.04E-10	5.14E-10	6.06E-10
Cl-36 (W)	1.00E+00	per associated element	5.04E-10	5.04E-10	4.56E-08	5.04E-10	5.04E-10	5.04E-10	5.36E-10	5.93E-09
Co-60	5.00E-02	oxides, hydroxides, halides, nitrates	4.09E-09	4.16E-09	3.57E-08	4.25E-09	3.54E-09	3.72E-09	7.65E-09	8.94E-09
Co-60	3.00E-01	all other compounds	4.76E-09	1.84E-08	3.45E-07	1.72E-08	1.35E-08	1.62E-08	3.60E-08	5.91E-08
Sr-90	3.00E-01	$SrTiO_3$	2.64E-09	2.64E-09	3.73E-09	3.36E-07	7.27E-07	2.64E-09	3.36E-09	6.47E-08
Sr-90	1.00E-02	all other compounds	2.69E-10	2.69E-10	2.86E-06	3.26E-08	7.09E-08	2.69E-10	5.73E-09	3.51E-07
Tc-99 (D)	8.00E-01	Oxides, halides, hydroxides, nitrates	4.52E-11	4.52E-11	3.51E-10	4.52E-11	4.52E-11	1.21E-09	5.78E-10	2.77E-10
									2.47E-09	ST wall
Tc-99(W)	8.00E-01	all other compounds	3.99E-11	3.99E-11	1.67E-08	3.99E-11	3.99E-11	1.07E-09	6.26E-10	2.25E-09
I-129 (D)	1.00E+00	all compounds	8.69E-11	2.09E-10	3.14E-10	1.40E-10	1.38E-10	1.56E-06	1.18E-10	4.69E-08

Table 3A. Dose Conversion Factors and Other Dose Calculation Parameters for SRS ORWBG (cont'd)

Radionuclide	f1	Inhalation Class	Gonad	CEDE Inhalation SV/Bq Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective
Cs-137	1.00E+00	all compounds	3.28E-12	4.02E-12	1.59E-10	3.95E-12	3.55E-12	3.57E-12	2.06E-11	2.74E-11
Np-237(W)	1.00E-03	all compounds	2.96E-05	1.69E-08	1.61E-05	2.62E-04	3.27E-03	1.34E-08	2.34E-05	1.46E-04
U-235	5.00E-02	UO_2, U_3O_8	2.37E-08	2.38E-08	2.95E-07	6.58E-07	1.01E-05	2.37E-08	8.59E-07	6.85E-07
U-235	5.00E-02	UO_3, UF_4 , UCl_4	7.24E-09	7.33E-09	1.48E-05	1.98E-07	3.05E-06	7.22E-09	2.65E-07	1.97E-06
U-235	2.00E-03	UF_6, UO_2F_2, $UO_2(NO_3)_2$	2.84E-09	5.37E-09	2.76E-04	7.15E-08	1.05E-06	4.11E-09	1.02E-07	3.22E-05
U-238	5.00E-02	UO_2, U_3O_8	2.23E-08	2.38E-08	2.80E-07	6.58E-07	9.78E-06	2.22E-08	8.22E-07	6.62E-07
U-238	5.00E-02	UO_3, UF_4 , UCl_4	6.71E-09	7.33E-09	1.42E-05	1.98E-07	2.94E-06	6.71E-09	2.54E-07	1.90E-06
U-238	2.00E-03	UF_6, UO_2F_2, $UO_2(NO_3)_2$	2.42E-09	5.37E-09	2.66E-04	6.88E-08	1.01E-06	2.73E-09	9.61E-08	3.20E-05
Pu-238 (W)	1.00E-03	All other compounds	2.80E-05	1.00E-09	1.84E-05	1.52E-04	1.90E-03	9.62E-10	7.02E-05	1.06E-04
Pu-238 (Y)	1.00E-05	Oxides	1.04E-05	4.40E-10	3.20E-04	5.80E-05	7.25E-04	3.86E-10	2.74E-05	7.79E-05
Pu-239 (W)	1.00E-03	All other compounds	3.18E-05	9.22E-10	1.72E-05	1.69E-04	2.11E-03	9.03E-10	7.56E-05	1.16E-04
Pu-239 (Y)	1.00E-05	Oxides	1.20E-05	3.99E-10	3.23E-04	6.57E-05	8.21E-04	3.75E-10	3.02E-05	8.33E-05

Table 3B. Dose Conversion Factors and Other Dose Calculation Parameters for SRS ORWBG

limiting DCF's are in **bold**

			CEDE Ingestion Sv/Bq							
Radionuclide	**f1**	**Ingestion Class**	**Gonad**	**Breast**	**Lung**	**R Marrow**	**B Surface**	**Thyroid**	**Remainder**	**Effective**
H-3	1.00E+00	Water Vapor	1.73E-11	1.73E-11	1.73E-11	1.73E-11	1.73E-11	1.73E-11	1.73E-11	1.73E-11
C-14	1.00E+00	organic forms	5.64E-10	5.64E-10	5.64E-10	5.64E-10	5.64E-10	5.64E-10	5.64E-10	5.64E-10
										1.73E-11
Cl-36	1.00E+00	all compounds	7.99E-10	7.99E-10	7.99E-10	7.99E-10	7.99E-10	7.99E-10	8.61E-10	
Co-60	5.00E-02	oxides, hydroxides, halides, nitrates	3.19E-09	1.10E-09	8.77E-10	1.32E-09	9.39E-10	7.88E-10	4.97E-09	2.77E-09
Co-60	3.00E-01	Organics and complex organics	7.23E-09	5.08E-09	4.96E-09	5.49E-09	4.81E-09	4.68E-09	1.06E-08	7.28E-09
Sr-90	3.00E-01	soluble salts	1.51E-09	1.51E-09	1.51E-09	1.94E-07	4.19E-07	1.51E-09	6.14E-09	3.85E-08
Sr-90	1.00E-02	$SrTiO_3$	5.04E-11	5.04E-11	5.04E-11	6.45E-09	1.39E-08	5.04E-11	6.70E-09	3.23E-09
Tc-99	8.00E-01	all compounds	6.04E-11	6.04E-11	6.04E-11	6.04E-11	6.04E-11	6.04E-11	1.02E-09	3.95E-10
I-129	1.00E+00	all compounds	1.38E-10	3.31E-10	1.65E-10	2.21E-10	2.17E-10	2.48E-06	1.99E-10	7.46E-08
Cs-137	1.00E+00	all compounds	1.71E-11	1.56E-12	2.12E-13	5.23E-12	1.43E-12	8.87E-15	7.55E-11	2.79E-11
Np-237	1.00E-03	all compounds	2.46E-07	1.45E-10	1.53E-10	2.18E-06	2.72E-05	1.10E-10	2.10E-07	1.20E-06

Table 3B. Dose Conversion Factors and Other Dose Calculation Parameters for SRS ORWBG (cont'd)

limiting DCF's are in **bold**

			CEDE Ingestion Sv/Bq							
Radionuclide	**f1**	**Ingestion Class**	**Gonad**	**Breast**	**Lung**	**R Marrow**	**B Surface**	**Thyroid**	**Remainder**	**Effective**
U-235	5.00E-02	Hexavalent forms	2.67E-09	2.49E-09	2.46E-09	6.81E-08	1.05E-06	2.45E-09	1.03E-07	7.19E-08
U-235	2.00E-03	Insoluble forms	3.34E-10	1.21E-10	1.01E-10	2.78E-09	4.20E-08	9.82E-11	1.84E-08	7.22E-09
U-238	5.00E-02	Hexavalent forms	2.31E-09	2.31E-09	2.30E-09	6.80E-08	1.01E-06	2.30E-09	9.69E-08	6.88E-08
U-238	2.00E-03	Insoluble forms	1.02E-10	9.33E-11	9.22E-11	2.72E-09	4.04E-08	9.20E-11	1.16E-08	6.42E-09
Pu-238	1.00E-03	Others	2.33E-07	8.41E-12	8.49E-12	1.27E-06	1.58E-05	7.99E-12	6.00E-07	8.65E-07
Pu-238	1.00E-04	Nitrates	2.33E-08	9.28E-13	8.50E-13	1.27E-07	1.58E-06	7.99E-13	7.44E-08	9.08E-08
Pu-238	1.00E-05	Oxides	2.33E-09	1.80E-13	8.64E-14	1.27E-08	1.58E-07	7.99E-14	2.18E-08	1.34E-08
Pu-239	1.00E-03	Others	2.64E-07	7.69E-12	7.74E-12	1.41E-06	1.76E-05	7.49E-12	6.43E-07	9.56E-07
Pu-239	1.00E-04	Nitrates	2.64E-08	8.09E-13	7.75E-13	1.41E-07	1.76E-06	7.49E-13	7.77E-08	9.96E-08
Pu-239	1.00E-05	Oxides	2.64E-09	1.21E-13	7.89E-08	1.41E-08	1.76E-07	7.50E-14	2.12E-08	1.40E-08
US EPA Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion. (EPAA-520/1-88-020), September 1988, Office of Radiation Programs, Federal Guidance Report No. 11.										

Table 4.
TRITIUM DOSE RATES FOR YEAR 2000
AT VARIOUS LOCATIONS IN FMB AND THE SAVANNAH RIVER

Location	Dose sv/year	mrem/year
Seep line (FMB)	5.10×10^{-4}	51.0
Road C (FMB)	1.20×10^{-4}	12.0
FM-6 (FMB)	0.34×10^{-4}	3.4
Highway 301 Bridge (SR)	1.06×10^{-7}	0.01
RM-60.9 (SR)*	9.3×10^{-8}	0.009

*RM-60.9 (SR) is a measuring point 20-30 miles upstream from Beaufort-Jasper.

Note: Concentration of any isotope in FMB was calculated with a flow rate at FMB of 7.8×10^6 m^3/year. To obtain the concentration at any other location, one must multiply the calculated concentration

$$C_{\text{location x}} = \text{Calculated Concentration x } \frac{7.8 \times 10^6 \ \frac{\text{m}^3}{\text{yr}}}{\text{flowrate at location x}}.$$

Flow rates for all locations are given in the Appendix.

Table 5.
MAXIMUM COI DOSE RATES AT VARIOUS LOCATIONS IN FMB AND THE SAVANNAH RIVER

Location	Pu^{239} (1) (mrem/yr)	Np^{237} (2) (mrem/yr)	I^{129} (3) (mrem/yr)	Tc^{99} (4) (mrem/yr)	C^{14} (5) (mrem/yr)	U^{238} (6)	U^{235} (6)
Seep line (FMB)	3.12	6.18	9.41	0.22	4.96	0.38	0.017
Road C (FMB)	0.73	1.46	2.22	0.052	1.17	0.09	0.004
FM-6 (FMB)	0.21	0.42	0.64	0.015	0.34	0.003	0.001
Highway 301 Bridge (SR)	6.47×10^{-4}	1.28×10^{-3}	1.95×10^{-3}	4.58×10^{-3}	1.03×10^{-3}	7.9×10^{-5}	3.4×10^{-6}
RM-60.9 (SR)	5.72×10^{-4}	1.13×10^{-3}	1.73×10^{-3}	4.04×10^{-3}	9.10×10^{-4}	7.0×10^{-5}	3.1×10^{-6}

Other COIs such as Cs^{137}, Pu^{238}, Sr^{90}, and Co^{60} never make it to FMB and the Savannah River from ORWBG.
(1). Maximum dose rate occurs 80,000 years after 1952.
(2). Maximum dose rate occurs 800 years after 1952.
(3). Maximum dose rate occurs 200 years after 1952.
(4). Maximum dose rate occurs 51 years after 1952.
(5). Maximum dose rate occurs 800 years after 1952.
(6). Maximum dose rate occurs 6,000 years after 1952.

Discussion

The dose that a person receives in one year from natural background radiation is, on the average, 300 mrem (6). The risk of fatality from this common and unavoidable background dose of 300 mrem is 1.5×10^{-4} (6). The dose rate due to tritium from ORWBG in the year 2000 that a person would receive from drinking one's entire need of water (2.2 liters/day) for a whole year at the seepline is 51 mrem. This dose rate drops to 3.4 mrem at FM-6 and to 0.01 mrem at Highway 301 bridge just below the site boundary in the Savannah River. Furthermore, this dose rate at the seepline in year 2007 drops to approximately 1 mrem/year.

The drinking water pathway is not the only route through which a person may receive dose. Other pathways include fish consumption, swimming, boating, and shoreline activities. The dose rate due to fish consumption, which could be as high as that of drinking water, is more than 99% caused by Cs^{137} and Sr^{90} in the fish (see Savannah River Site, Environmental Data for 1998, p. 134). Since the Cs^{137} and Sr^{90} in the ORWBG never make it to FMB, it cannot contribute to the dose rate from fish. The contributions from swimming, boating, and shoreline activities to dose rate is less than 0.2% (see Savannah River Site, Environmental Data for 1998, p. 134).

Conclusions and Recommendations

This work showed that it is possible to develop a simplified model for the estimation of surface water contamination. This report provides one such model which has been calibrated using existing data from one source, tritium.

In addition to validation of the developed model for tritium, other calibration of the model for all the COI's should be undertaken immediately.

The first step in the process of continuing the calibration for other isotopes is to obtain accurate and consistent concentrations of each isotope measured at specific locations with known flow rates. The measured concentration must be attributable to known origin. More detailed modeling of landfill performance, leachate generation, and solute transport may be used to confirm the level of conservativeness of the existing model. Additionally, model sensitivity to parameter uncertainty should be evaluated and documented. Other potential exposure pathways may also be considered.

In Table 3 the calculated peak concentrations of Cd, Hg, and Pb are 0.33 μg/L, 1.4 μg/L, and 0.63 μg/L respectively. It is believed that these calculations are conservative in that the predicted values are higher than one would expect to measure. However, the only way we can verify the accuracy of the model used would be to calibrate for each element and each isotope. Based on the results we obtained thus far however, there appears to be no environmental problems animating from the transport of Cd, Hg, and Pb from the ORWBG to FMB and the Savannah River.

Also peak concentration of VOCs released to FMB is 93 μg/L and this occurs in the year 2003. EPA limit on VOCs is 100 μg/L. This is too close for comfort. What is needed again is measured values of VOCs to help us calibrate the model and thus gain confidence in our projection.

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Appendix

10-Year Average Flow Rates
At Various Sampling Points Along FMB And The Savannah River

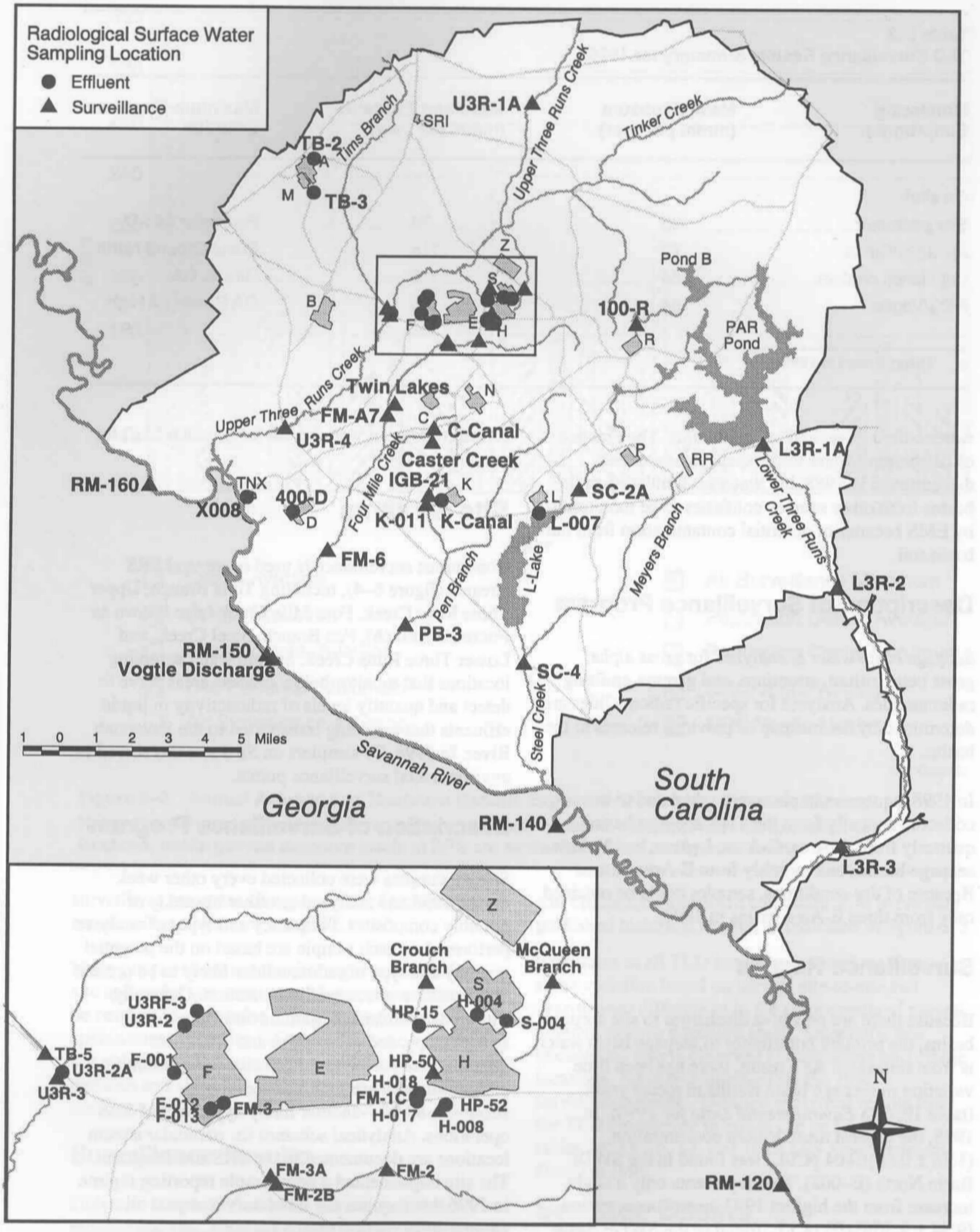
Station	10-Year Ave. Flow Rate (m^3/year)
FM-2	6.47×10^6
F-08	2.33×10^6
F-3A	2.38×10^6
FM-6	3.26×10^7
RM-120	1.06×10^{10}
RM-60.9	1.2×10^{10}
Road C	9.34×10^6

RM-120 corresponds to Highway 301 Bridge.
RM-60.9 corresponds to approximately 20-30 miles upstream from Beaufort-Jasper.
The other stations are located on the map in the Appendix.

Data provided by Peter Fledderman. According to Dr. Fledderman the seep line flow rate (2.22×10^6 m^3/yr) is derived from flow rates at FM3A, FM3, F12, and F13. Flow rate seep line = FM3A - FM3 - F12 - F13. Flow rates at FM3, F12 and F13 are for three-year averages (1997, 1998, 1999):

- FM3 = 2.1×10^6 m^3/year
- FM12 = 1.0×10^5 m^3/year
- FM13 = 3.2×10^4 m^3/year

Measured Tritium Flux to FMB (in Ci/year)			
Year	Measured Flux	Year	Measured Flux
1968	83	1984	4481
1969	165	1985	4687
1970	73	1986	5210
1971	2007	1987	6150
1972	506	1988	3670
1973	1115	1989	3600
1974	1385	1990	4280
1975	2521	1991	6420
1976	1729	1992	4090
1977	433	1993	5330
1978	219	1994	3090
1979	2851	1995	4010
1980	3652	1996	3200
1981	2070	1997	2960
1982	3281	1998	3490
1983	4018		
Data taken from reference (1).			



EPD/GIS Map

Figure 6–4 Radiological Surface Water Sampling Locations
Surveillance and effluent sampling points are at SRS seepage basins and streams and on the Savannah River.

Computer Output For All COI Calculations

H^3

Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	4.75E+05	λ_D (yr^{-1})	0.0559
Δt_R (yr)	0.05	I_m (Ci/yr)	39666
Δt_O (yr)	12		
$T_{1/2}$ (yr)	1.24E+01		

Summary

Total Flux to Water Table (Ci) =	**2.95E+05**
Total Flux to Creek (Ci) =	**1.14E+05**
Maximum Flux to Water Table (Ci/yr) =	**2.43E+04**
Maximum Flux to Creek (Ci/yr) =	**6.77E+03**
Maximum Creek Concentration (pCi/L) =	**8.68E+05**

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.3125
f_L	1.00	I_{max} (Ci)	106365
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^w (L/kg)	0		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	5.6
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	1
n	0.25	D_{xx}' (ft^2/yr)	21600
a_L (ft)	135	D_{yy}' (ft^2/yr)	2720
a_T (ft)	17	v_x' (ft/yr)	160.000
L (ft)	1100	c_o/M (ft^{-3})	4.13E-08
W (ft)	1000		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	0		

Creek Discharge

Q_c (m^3/yr)	7.80E+06

Integral Convergence Criteria

ε_1	0.01	**Local Concentration**
ε_2	0.1	**Creek Flux**

Inventory and Water Table Flux

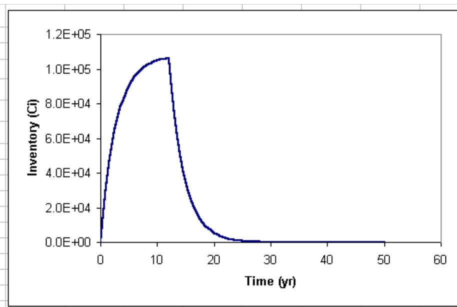
Inventory (Ci)

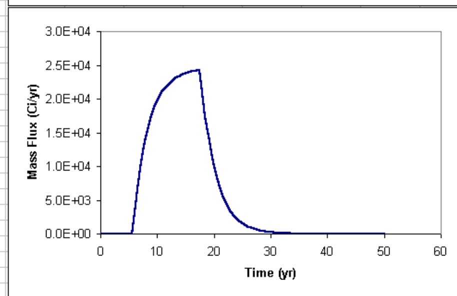
t_{min} (yr): 0

t_{max} (yr): 50

Water Table Flux (Ci/yr)

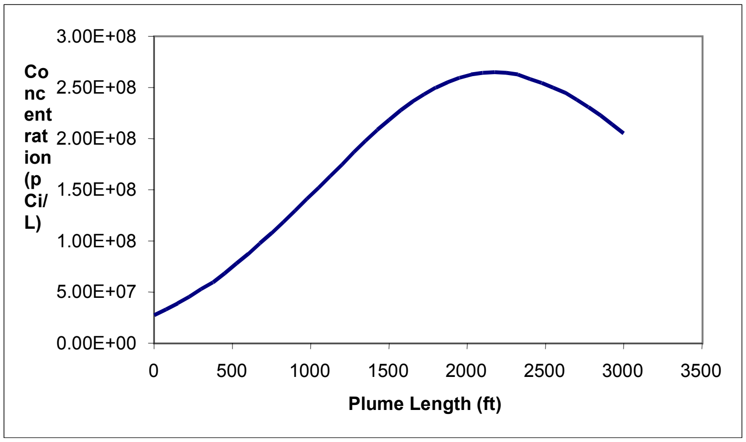
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	0.5	1.73E+04	0.00E+00	0.00E+00
2	1	3.25E+04	0.00E+00	0.00E+00
3	1.5	4.51E+04	0.00E+00	0.00E+00
4	2	5.57E+04	0.00E+00	0.00E+00
5	2.5	6.44E+04	0.00E+00	0.00E+00
6	3	7.17E+04	0.00E+00	0.00E+00
7	3.5	7.77E+04	0.00E+00	0.00E+00
8	4	8.28E+04	0.00E+00	0.00E+00
9	4.5	8.70E+04	0.00E+00	0.00E+00
10	5	9.04E+04	0.00E+00	0.00E+00
11	5.5	9.33E+04	0.00E+00	0.00E+00
12	6	9.58E+04	3.17E+03	7.94E+02
13	6.5	9.78E+04	6.78E+03	3.28E+03
14	7	9.94E+04	9.78E+03	7.42E+03
15	7.5	1.01E+05	1.23E+04	1.29E+04
16	8	1.02E+05	1.43E+04	1.96E+04
17	8.5	1.03E+05	1.61E+04	2.72E+04
18	9	1.04E+05	1.75E+04	3.56E+04
19	9.5	1.04E+05	1.87E+04	4.46E+04
20	10	1.05E+05	1.97E+04	5.42E+04
21	10.5	1.05E+05	2.05E+04	6.43E+04
22	11	1.06E+05	2.12E+04	7.47E+04
23	11.5	1.06E+05	2.18E+04	8.55E+04
24	12	1.06E+05	2.23E+04	9.65E+04
25	12.5	8.85E+04	2.26E+04	1.08E+05
26	13	7.36E+04	2.30E+04	1.19E+05
27	13.5	6.12E+04	2.33E+04	1.31E+05
28	14	5.09E+04	2.35E+04	1.42E+05
29	14.5	4.23E+04	2.37E+04	1.54E+05
30	15	3.52E+04	2.38E+04	1.66E+05
31	15.5	2.93E+04	2.40E+04	1.78E+05
32	16	2.44E+04	2.41E+04	1.90E+05
33	16.5	2.03E+04	2.42E+04	2.02E+05
34	17	1.69E+04	2.42E+04	2.14E+05
35	17.5	1.40E+04	2.43E+04	2.26E+05
36	18	1.17E+04	2.10E+04	2.38E+05
37	18.5	9.70E+03	1.74E+04	2.47E+05
38	19	8.07E+03	1.45E+04	2.55E+05
39	19.5	6.71E+03	1.21E+04	2.62E+05
40	20	5.58E+03	1.00E+04	2.67E+05
41	20.5	4.64E+03	8.35E+03	2.72E+05
42	21	3.86E+03	6.95E+03	2.76E+05
43	21.5	3.21E+03	5.78E+03	2.79E+05
44	22	2.67E+03	4.81E+03	2.82E+05
45	22.5	2.22E+03	4.00E+03	2.84E+05
46	23	1.85E+03	3.32E+03	2.86E+05
47	23.5	1.54E+03	2.77E+03	2.87E+05
48	24	1.28E+03	2.30E+03	2.88E+05
49	24.5	1.06E+03	1.91E+03	2.89E+05
50	25	8.85E+02	1.59E+03	2.90E+05
51	25.5	7.36E+02	1.32E+03	2.91E+05
52	26	6.12E+02	1.10E+03	2.92E+05
53	26.5	5.09E+02	9.16E+02	2.92E+05
54	27	4.24E+02	7.62E+02	2.93E+05
55	27.5	3.52E+02	6.34E+02	2.93E+05
56	28	2.93E+02	5.27E+02	2.93E+05
57	28.5	2.44E+02	4.38E+02	2.93E+05
58	29	2.03E+02	3.65E+02	2.94E+05
59	29.5	1.69E+02	3.03E+02	2.94E+05
60	30	1.40E+02	2.52E+02	2.94E+05
61	30.5	1.17E+02	2.10E+02	2.94E+05
62	31	9.70E+01	1.74E+02	2.94E+05
63	31.5	8.07E+01	1.45E+02	2.94E+05
64	32	6.71E+01	1.21E+02	2.94E+05
65	32.5	5.58E+01	1.00E+02	2.94E+05
66	33	4.64E+01	8.35E+01	2.94E+05
67	33.5	3.86E+01	6.95E+01	2.94E+05
68	34	3.21E+01	5.78E+01	2.95E+05
69	34.5	2.67E+01	4.81E+01	2.95E+05
70	35	2.22E+01	4.00E+01	2.95E+05
71	35.5	1.85E+01	3.33E+01	2.95E+05
72	36	1.54E+01	2.77E+01	2.95E+05
73	36.5	1.28E+01	2.30E+01	2.95E+05
74	37	1.06E+01	1.91E+01	2.95E+05
75	37.5	8.85E+00	1.59E+01	2.95E+05
76	38	7.36E+00	1.32E+01	2.95E+05
77	38.5	6.12E+00	1.10E+01	2.95E+05
78	39	5.09E+00	9.16E+00	2.95E+05
79	39.5	4.24E+00	7.62E+00	2.95E+05
80	40	3.52E+00	6.34E+00	2.95E+05
81	40.5	2.93E+00	5.27E+00	2.95E+05
82	41	2.44E+00	4.38E+00	2.95E+05
83	41.5	2.03E+00	3.65E+00	2.95E+05
84	42	1.69E+00	3.03E+00	2.95E+05
85	42.5	1.40E+00	2.52E+00	2.95E+05
86	43	1.17E+00	2.10E+00	2.95E+05
87	43.5	9.71E-01	1.75E+00	2.95E+05
88	44	8.07E-01	1.45E+00	2.95E+05
89	44.5	6.71E-01	1.21E+00	2.95E+05
90	45	5.58E-01	1.00E+00	2.95E+05
91	45.5	4.65E-01	8.35E-01	2.95E+05
92	46	3.86E-01	6.95E-01	2.95E+05
93	46.5	3.21E-01	5.78E-01	2.95E+05
94	47	2.67E-01	4.81E-01	2.95E+05
95	47.5	2.22E-01	4.00E-01	2.95E+05
96	48	1.85E-01	3.33E-01	2.95E+05
97	48.5	1.54E-01	2.77E-01	2.95E+05
98	49	1.28E-01	2.30E-01	2.95E+05
99	49.5	1.06E-01	1.91E-01	2.95E+05
100	50	8.85E-02	1.59E-01	2.95E+05





Plume Profile

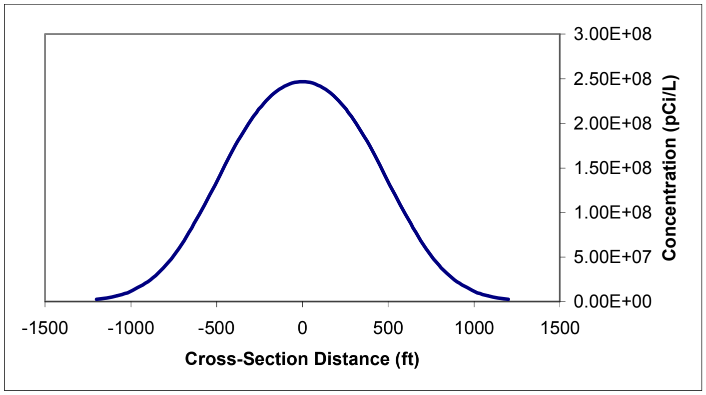
x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	30



	x (ft)	C(x;y,t)
0	0	2.77E+07
1	75	3.31E+07
2	150	3.91E+07
3	225	4.55E+07
4	300	5.28E+07
5	375	5.97E+07
6	450	6.82E+07
7	525	7.78E+07
8	600	8.74E+07
9	675	9.74E+07
10	750	1.08E+08
11	825	1.19E+08
12	900	1.30E+08
13	975	1.41E+08
14	1050	1.52E+08
15	1125	1.63E+08
16	1200	1.75E+08
17	1275	1.87E+08
18	1350	1.98E+08
19	1425	2.08E+08
20	1500	2.18E+08
21	1575	2.28E+08
22	1650	2.36E+08
23	1725	2.43E+08
24	1800	2.50E+08
25	1875	2.55E+08
26	1950	2.59E+08
27	2025	2.63E+08
28	2100	2.64E+08
29	2175	2.65E+08
30	2250	2.64E+08
31	2325	2.63E+08
32	2400	2.58E+08
33	2475	2.55E+08
34	2550	2.50E+08
35	2625	2.45E+08
36	2700	2.38E+08
37	2775	2.31E+08
38	2850	2.23E+08
39	2925	2.14E+08
40	3000	2.05E+08

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	1200
t (yr) =	30

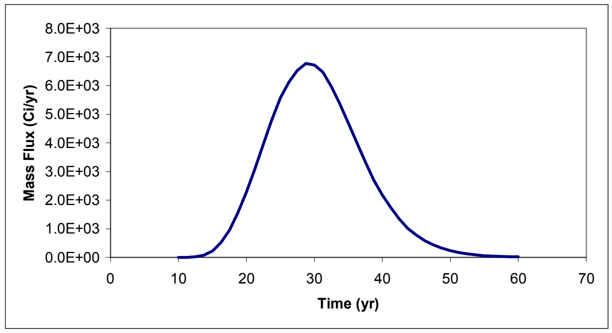


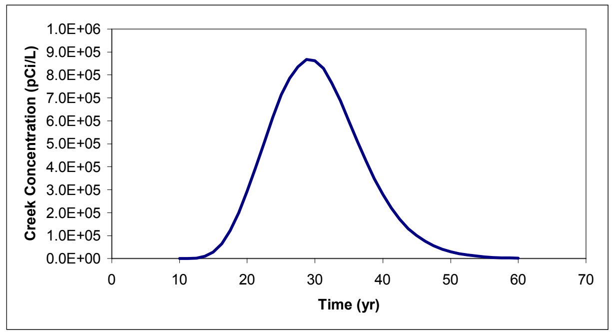
	y (ft)	C(x,y,t)
0	-1200	2.37E+06
1	-1140	3.93E+06
2	-1080	6.34E+06
3	-1020	9.94E+06
4	-960	1.59E+07
5	-900	2.23E+07
6	-840	3.20E+07
7	-780	4.44E+07
8	-720	5.96E+07
9	-660	7.76E+07
10	-600	9.79E+07
11	-540	1.20E+08
12	-480	1.42E+08
13	-420	1.64E+08
14	-360	1.85E+08
15	-300	2.04E+08
16	-240	2.19E+08
17	-180	2.31E+08
18	-120	2.40E+08
19	-60	2.45E+08
20	0	2.47E+08
21	60	2.45E+08
22	120	2.40E+08
23	180	2.31E+08
24	240	2.19E+08
25	300	2.04E+08
26	360	1.85E+08
27	420	1.64E+08
28	480	1.42E+08
29	540	1.20E+08
30	600	9.79E+07
31	660	7.76E+07
32	720	5.96E+07
33	780	4.44E+07
34	840	3.20E+07
35	900	2.23E+07
36	960	1.59E+07
37	1020	9.94E+06
38	1080	6.34E+06
39	1140	3.93E+06
40	1200	2.37E+06

Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	1200
t_{min} (yr) =	10
t_{max} (yr) =	60

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	10	9.71E-02	0.00E+00	1.24E+01
1	11.25	2.32E+00	1.51E+00	2.98E+02
2	12.5	1.84E+01	1.45E+01	2.36E+03
3	13.75	7.86E+01	7.51E+01	1.01E+04
4	15	2.28E+02	2.66E+02	2.92E+04
5	16.25	5.09E+02	7.27E+02	6.53E+04
6	17.5	9.50E+02	1.64E+03	1.22E+05
7	18.75	1.56E+03	3.21E+03	2.00E+05
8	20	2.29E+03	5.61E+03	2.93E+05
9	21.25	3.10E+03	8.98E+03	3.98E+05
10	22.5	3.96E+03	1.34E+04	5.07E+05
11	23.75	4.79E+03	1.89E+04	6.14E+05
12	25	5.56E+03	2.53E+04	7.13E+05
13	26.25	6.12E+03	3.26E+04	7.85E+05
14	27.5	6.52E+03	4.05E+04	8.36E+05
15	28.75	6.77E+03	4.88E+04	8.68E+05
16	30	6.72E+03	5.73E+04	8.62E+05
17	31.25	6.47E+03	6.55E+04	8.29E+05
18	32.5	5.96E+03	7.33E+04	7.65E+05
19	33.75	5.36E+03	8.04E+04	6.87E+05
20	35	4.68E+03	8.66E+04	6.00E+05
21	36.25	3.98E+03	9.20E+04	5.11E+05
22	37.5	3.32E+03	9.66E+04	4.26E+05
23	38.75	2.71E+03	1.00E+05	3.48E+05
24	40	2.18E+03	1.03E+05	2.80E+05
25	41.25	1.73E+03	1.06E+05	2.21E+05
26	42.5	1.34E+03	1.08E+05	1.72E+05
27	43.75	1.01E+03	1.09E+05	1.30E+05
28	45	7.82E+02	1.10E+05	1.00E+05
29	46.25	5.87E+02	1.11E+05	7.52E+04
30	47.5	4.39E+02	1.12E+05	5.63E+04
31	48.75	3.22E+02	1.12E+05	4.13E+04
32	50	2.36E+02	1.13E+05	3.02E+04
33	51.25	1.70E+02	1.13E+05	2.19E+04
34	52.5	1.23E+02	1.13E+05	1.57E+04
35	53.75	8.84E+01	1.13E+05	1.13E+04
36	55	6.25E+01	1.13E+05	8.01E+03
37	56.25	4.42E+01	1.13E+05	5.66E+03
38	57.5	3.15E+01	1.14E+05	4.04E+03
39	58.75	2.21E+01	1.14E+05	2.83E+03
40	60	1.54E+01	1.14E+05	1.98E+03





Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	3.01E+06	λ_D (yr^{-1})	0.0562
Δt_R (yr)	5	I_m (Ci/yr)	172000
Δt_O (yr)	20		
$T_{1/2}$ (yr)	1.23E+01		

Summary

Total Flux to Water Table (Ci) =	**1.57E+06**
Total Flux to Creek (Ci) =	**2.96E+05**
Maximum Flux to Water Table (Ci/yr) =	**8.89E+04**
Maximum Flux to Creek (Ci/yr) =	**1.38E+04**
Maximum Creek Concentration (pCi/L) =	**1.77E+06**

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.2367424
f_L	1.00	I_{max} (Ci)	583396
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^w (L/kg)	0.05		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	7.84
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	1.32
n	0.25	D_{xx}' (ft^2/yr)	16363.636
a_L (ft)	135	D_{yy}' (ft^2/yr)	2061
a_T (ft)	17	v_x' (ft/yr)	121.212
L (ft)	1000	c_o/M (ft^{-3})	9.84E-09
W (ft)	3500		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	0.05		

Creek Discharge

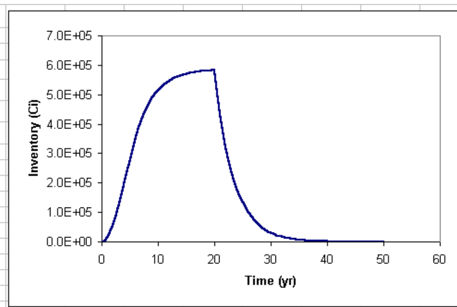
Q_c (m^3/yr)	7.80E+06

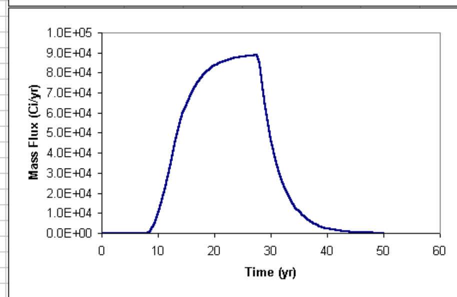
Integral Convergence Criteria

ε_1	0.01	**Local Concentration**
ε_2	0.1	**Creek Flux**

Inventory and Water Table Flux

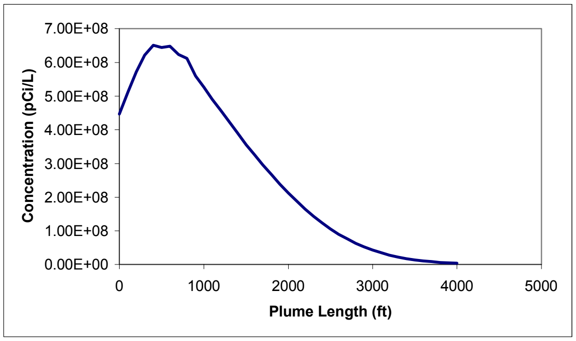
	Inventory (Ci)			Water Table Flux (Ci/yr)	
	t_{min} (yr)	0			
	t_{max} (yr)	50			
	t (yr)	I (Ci)		$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00		0.00E+00	0
1	0.5	4.10E+03		0.00E+00	0.00E+00
2	1	1.56E+04		0.00E+00	0.00E+00
3	1.5	3.36E+04		0.00E+00	0.00E+00
4	2	5.71E+04		0.00E+00	0.00E+00
5	2.5	8.54E+04		0.00E+00	0.00E+00
6	3	1.18E+05		0.00E+00	0.00E+00
7	3.5	1.54E+05		0.00E+00	0.00E+00
8	4	1.93E+05		0.00E+00	0.00E+00
9	4.5	2.35E+05		0.00E+00	0.00E+00
10	5	2.79E+05		0.00E+00	0.00E+00
11	5.5	3.21E+05		0.00E+00	0.00E+00
12	6	3.57E+05		0.00E+00	0.00E+00
13	6.5	3.89E+05		0.00E+00	0.00E+00
14	7	4.16E+05		0.00E+00	0.00E+00
15	7.5	4.39E+05		0.00E+00	0.00E+00
16	8	4.59E+05		6.61E+01	1.65E+01
17	8.5	4.77E+05		1.07E+03	3.01E+02
18	9	4.92E+05		3.16E+03	1.36E+03
19	9.5	5.05E+05		6.18E+03	3.69E+03
20	10	5.16E+05		1.00E+04	7.74E+03
21	10.5	5.26E+05		1.45E+04	1.39E+04
22	11	5.34E+05		1.97E+04	2.24E+04
23	11.5	5.41E+05		2.53E+04	3.37E+04
24	12	5.48E+05		3.14E+04	4.79E+04
25	12.5	5.53E+05		3.79E+04	6.52E+04
26	13	5.58E+05		4.47E+04	8.58E+04
27	13.5	5.62E+05		5.08E+04	1.10E+05
28	14	5.65E+05		5.61E+04	1.36E+05
29	14.5	5.68E+05		6.06E+04	1.66E+05
30	15	5.71E+05		6.45E+04	1.97E+05
31	15.5	5.73E+05		6.79E+04	2.30E+05
32	16	5.75E+05		7.09E+04	2.65E+05
33	16.5	5.77E+05		7.34E+04	3.01E+05
34	17	5.78E+05		7.56E+04	3.38E+05
35	17.5	5.79E+05		7.75E+04	3.76E+05
36	18	5.80E+05		7.91E+04	4.15E+05
37	18.5	5.81E+05		8.05E+04	4.55E+05
38	19	5.82E+05		8.18E+04	4.96E+05
39	19.5	5.83E+05		8.28E+04	5.37E+05
40	20	5.83E+05		8.37E+04	5.79E+05
41	20.5	5.04E+05		8.45E+04	6.21E+05
42	21	4.35E+05		8.52E+04	6.63E+05
43	21.5	3.76E+05		8.58E+04	7.06E+05
44	22	3.25E+05		8.63E+04	7.49E+05
45	22.5	2.81E+05		8.67E+04	7.92E+05
46	23	2.42E+05		8.71E+04	8.36E+05
47	23.5	2.09E+05		8.74E+04	8.79E+05
48	24	1.81E+05		8.77E+04	9.23E+05
49	24.5	1.56E+05		8.80E+04	9.67E+05
50	25	1.35E+05		8.82E+04	1.01E+06
51	25.5	1.16E+05		8.83E+04	1.06E+06
52	26	1.01E+05		8.85E+04	1.10E+06
53	26.5	8.69E+04		8.86E+04	1.14E+06
54	27	7.51E+04		8.88E+04	1.19E+06
55	27.5	6.48E+04		8.89E+04	1.23E+06
56	28	5.60E+04		8.48E+04	1.28E+06
57	28.5	4.84E+04		7.33E+04	1.32E+06
58	29	4.18E+04		6.33E+04	1.35E+06
59	29.5	3.61E+04		5.47E+04	1.38E+06
60	30	3.12E+04		4.72E+04	1.40E+06
61	30.5	2.69E+04		4.08E+04	1.43E+06
62	31	2.33E+04		3.52E+04	1.45E+06
63	31.5	2.01E+04		3.04E+04	1.46E+06
64	32	1.74E+04		2.63E+04	1.48E+06
65	32.5	1.50E+04		2.27E+04	1.49E+06
66	33	1.29E+04		1.96E+04	1.50E+06
67	33.5	1.12E+04		1.69E+04	1.51E+06
68	34	9.66E+03		1.46E+04	1.52E+06
69	34.5	8.34E+03		1.26E+04	1.52E+06
70	35	7.21E+03		1.09E+04	1.53E+06
71	35.5	6.23E+03		9.43E+03	1.53E+06
72	36	5.38E+03		8.15E+03	1.54E+06
73	36.5	4.65E+03		7.04E+03	1.54E+06
74	37	4.01E+03		6.08E+03	1.55E+06
75	37.5	3.47E+03		5.25E+03	1.55E+06
76	38	2.99E+03		4.53E+03	1.55E+06
77	38.5	2.59E+03		3.92E+03	1.55E+06
78	39	2.23E+03		3.38E+03	1.55E+06
79	39.5	1.93E+03		2.92E+03	1.56E+06
80	40	1.67E+03		2.52E+03	1.56E+06
81	40.5	1.44E+03		2.18E+03	1.56E+06
82	41	1.24E+03		1.88E+03	1.56E+06
83	41.5	1.07E+03		1.63E+03	1.56E+06
84	42	9.28E+02		1.41E+03	1.56E+06
85	42.5	8.01E+02		1.21E+03	1.56E+06
86	43	6.92E+02		1.05E+03	1.56E+06
87	43.5	5.98E+02		9.05E+02	1.56E+06
88	44	5.16E+02		7.82E+02	1.56E+06
89	44.5	4.46E+02		6.76E+02	1.56E+06
90	45	3.85E+02		5.84E+02	1.56E+06
91	45.5	3.33E+02		5.04E+02	1.56E+06
92	46	2.87E+02		4.35E+02	1.56E+06
93	46.5	2.48E+02		3.76E+02	1.56E+06
94	47	2.14E+02		3.25E+02	1.56E+06
95	47.5	1.85E+02		2.81E+02	1.57E+06
96	48	1.60E+02		2.42E+02	1.57E+06
97	48.5	1.38E+02		2.09E+02	1.57E+06
98	49	1.19E+02		1.81E+02	1.57E+06
99	49.5	1.03E+02		1.56E+02	1.57E+06
100	50	8.91E+01		1.35E+02	1.57E+06





Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	4000
y (ft) =	0
t (yr) =	30



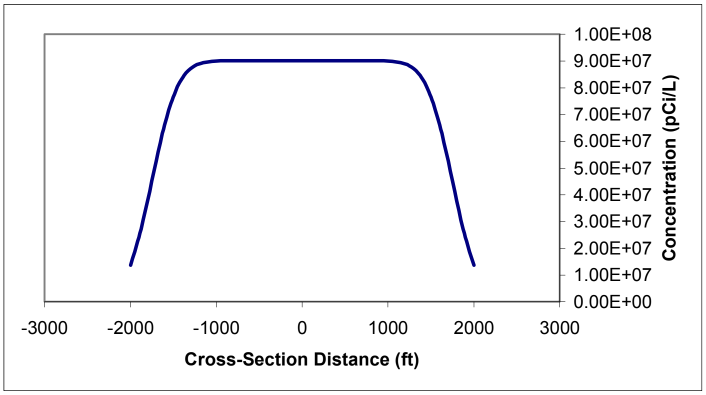
500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	4.47E+08
1	100	5.12E+08
2	200	5.72E+08
3	300	6.21E+08
4	400	6.51E+08
5	500	6.44E+08
6	600	6.48E+08
7	700	6.23E+08
8	800	6.12E+08
9	900	5.60E+08
10	1000	5.26E+08
11	1100	4.90E+08
12	1200	4.57E+08
13	1300	4.24E+08
14	1400	3.90E+08
15	1500	3.56E+08
16	1600	3.27E+08
17	1700	2.96E+08
18	1800	2.67E+08
19	1900	2.39E+08
20	2000	2.13E+08
21	2100	1.88E+08
22	2200	1.65E+08
23	2300	1.43E+08
24	2400	1.24E+08
25	2500	1.06E+08
26	2600	9.01E+07
27	2700	7.59E+07
28	2800	6.34E+07
29	2900	5.25E+07
30	3000	4.31E+07
31	3100	3.50E+07
32	3200	2.82E+07
33	3300	2.25E+07
34	3400	1.78E+07
35	3500	1.39E+07
36	3600	1.08E+07
37	3700	8.28E+06
38	3800	6.29E+06
39	3900	4.73E+06
40	4000	3.52E+06

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2000
t (yr) =	30

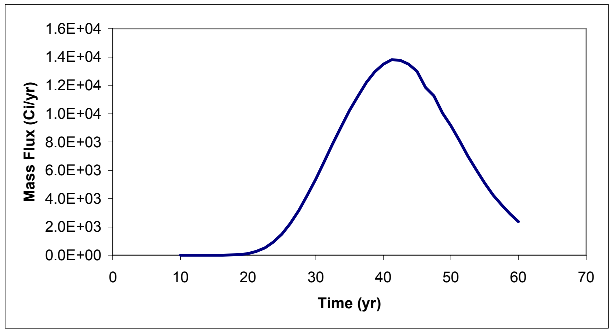
	y (ft)	C(x,y,t)
0	-2000	1.36E+07
1	-1900	2.41E+07
2	-1800	3.77E+07
3	-1700	5.25E+07
4	-1600	6.61E+07
5	-1500	7.65E+07
6	-1400	8.33E+07
7	-1300	8.71E+07
8	-1200	8.90E+07
9	-1100	8.97E+07
10	-1000	9.00E+07
11	-900	9.01E+07
12	-800	9.01E+07
13	-700	9.01E+07
14	-600	9.01E+07
15	-500	9.01E+07
16	-400	9.01E+07
17	-300	9.01E+07
18	-200	9.01E+07
19	-100	9.01E+07
20	0	9.01E+07
21	100	9.01E+07
22	200	9.01E+07
23	300	9.01E+07
24	400	9.01E+07
25	500	9.01E+07
26	600	9.01E+07
27	700	9.01E+07
28	800	9.01E+07
29	900	9.01E+07
30	1000	9.00E+07
31	1100	8.97E+07
32	1200	8.90E+07
33	1300	8.71E+07
34	1400	8.33E+07
35	1500	7.65E+07
36	1600	6.61E+07
37	1700	5.25E+07
38	1800	3.77E+07
39	1900	2.41E+07
40	2000	1.36E+07

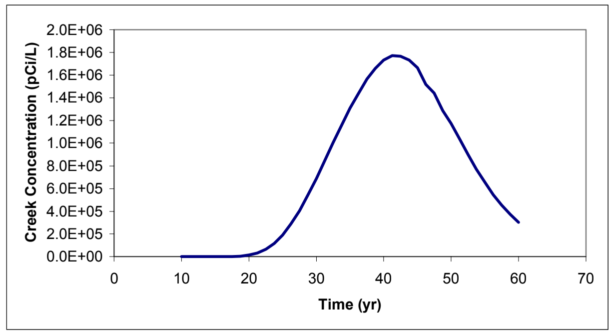


Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	1200
t_{min} (yr) =	10
t_{max} (yr) =	60

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	10	2.11E-13	0.00E+00	2.70E-11
1	11.25	2.53E-07	1.58E-07	3.24E-05
2	12.5	2.44E-04	1.53E-04	3.13E-02
3	13.75	1.64E-02	1.06E-02	2.11E+00
4	15	2.88E-01	2.01E-01	3.69E+01
5	16.25	2.32E+00	1.83E+00	2.98E+02
6	17.5	1.14E+01	1.04E+01	1.47E+03
7	18.75	4.03E+01	4.27E+01	5.16E+03
8	20	1.12E+02	1.38E+02	1.43E+04
9	21.25	2.58E+02	3.68E+02	3.30E+04
10	22.5	5.16E+02	8.52E+02	6.61E+04
11	23.75	9.21E+02	1.75E+03	1.18E+05
12	25	1.50E+03	3.26E+03	1.92E+05
13	26.25	2.25E+03	5.60E+03	2.88E+05
14	27.5	3.17E+03	8.98E+03	4.06E+05
15	28.75	4.22E+03	1.36E+04	5.42E+05
16	30	5.38E+03	1.96E+04	6.90E+05
17	31.25	6.60E+03	2.71E+04	8.46E+05
18	32.5	7.84E+03	3.61E+04	1.00E+06
19	33.75	9.05E+03	4.67E+04	1.16E+06
20	35	1.02E+04	5.87E+04	1.31E+06
21	36.25	1.12E+04	7.21E+04	1.44E+06
22	37.5	1.22E+04	8.68E+04	1.57E+06
23	38.75	1.29E+04	1.02E+05	1.66E+06
24	40	1.35E+04	1.19E+05	1.73E+06
25	41.25	1.38E+04	1.36E+05	1.77E+06
26	42.5	1.38E+04	1.53E+05	1.77E+06
27	43.75	1.35E+04	1.70E+05	1.73E+06
28	45	1.30E+04	1.87E+05	1.67E+06
29	46.25	1.18E+04	2.02E+05	1.52E+06
30	47.5	1.12E+04	2.17E+05	1.44E+06
31	48.75	1.00E+04	2.30E+05	1.29E+06
32	50	9.16E+03	2.42E+05	1.17E+06
33	51.25	8.09E+03	2.53E+05	1.04E+06
34	52.5	7.01E+03	2.62E+05	8.99E+05
35	53.75	6.01E+03	2.71E+05	7.71E+05
36	55	5.10E+03	2.78E+05	6.54E+05
37	56.25	4.25E+03	2.83E+05	5.45E+05
38	57.5	3.54E+03	2.88E+05	4.54E+05
39	58.75	2.92E+03	2.92E+05	3.74E+05
40	60	2.37E+03	2.96E+05	3.03E+05





Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	1.00E+06	λ_D (yr^{-1})	0.0562
Δt_R (yr)	0.05	I_m (Ci/yr)	83507
Δt_O (yr)	12		
$T_{1/2}$ (yr)	1.23E+01		

Summary

Total Flux to Water Table (Ci) =	6.19E+05
Total Flux to Creek (Ci) =	2.38E+05
Maximum Flux to Water Table (Ci/yr) =	5.10E+04
Maximum Flux to Creek (Ci/yr) =	1.41E+04
Maximum Creek Concentration (pCi/L) =	1.80E+06

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.3125
f_L	1.00	I_{max} (Ci)	223769
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^w (L/kg)	0		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	5.6
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	1
n	0.25	D_{xx}' (ft^2/yr)	21600
a_L (ft)	135	D_{yy}' (ft^2/yr)	2720
a_T (ft)	17	v_x' (ft/yr)	160.000
L (ft)	1100	c_o/M (ft^{-3})	4.13E-08
W (ft)	1000		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	0		

Creek Discharge

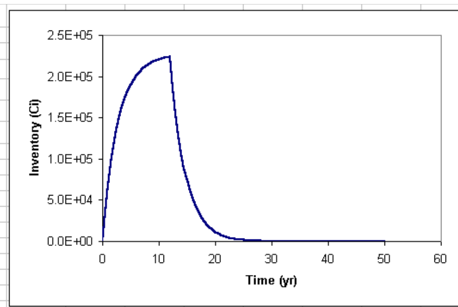
Q_c (m^3/yr)	7.80E+06

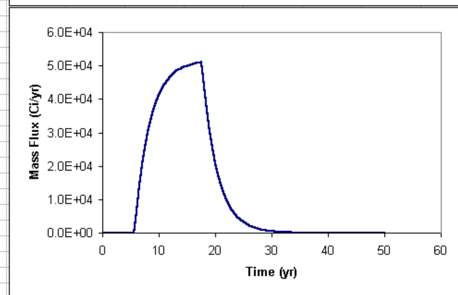
Integral Convergence Criteria

ε_1	0.01	Local Concentration
ε_2	0.1	Creek Flux

Inventory and Water Table Flux

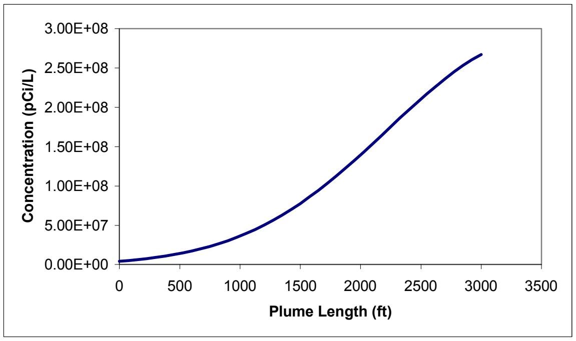
	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	50		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	0.5	3.64E+04	0.00E+00	0.00E+00
2	1	6.84E+04	0.00E+00	0.00E+00
3	1.5	9.50E+04	0.00E+00	0.00E+00
4	2	1.17E+05	0.00E+00	0.00E+00
5	2.5	1.36E+05	0.00E+00	0.00E+00
6	3	1.51E+05	0.00E+00	0.00E+00
7	3.5	1.64E+05	0.00E+00	0.00E+00
8	4	1.74E+05	0.00E+00	0.00E+00
9	4.5	1.83E+05	0.00E+00	0.00E+00
10	5	1.90E+05	0.00E+00	0.00E+00
11	5.5	1.96E+05	0.00E+00	0.00E+00
12	6	2.01E+05	6.67E+03	1.67E+03
13	6.5	2.06E+05	1.42E+04	6.90E+03
14	7	2.09E+05	2.06E+04	1.56E+04
15	7.5	2.12E+05	2.58E+04	2.72E+04
16	8	2.15E+05	3.01E+04	4.12E+04
17	8.5	2.17E+05	3.38E+04	5.71E+04
18	9	2.18E+05	3.68E+04	7.48E+04
19	9.5	2.20E+05	3.93E+04	9.38E+04
20	10	2.21E+05	4.14E+04	1.14E+05
21	10.5	2.22E+05	4.31E+04	1.35E+05
22	11	2.23E+05	4.46E+04	1.57E+05
23	11.5	2.23E+05	4.58E+04	1.80E+05
24	12	2.24E+05	4.68E+04	2.03E+05
25	12.5	1.86E+05	4.76E+04	2.26E+05
26	13	1.55E+05	4.83E+04	2.50E+05
27	13.5	1.29E+05	4.88E+04	2.75E+05
28	14	1.07E+05	4.93E+04	2.99E+05
29	14.5	8.90E+04	4.97E+04	3.24E+05
30	15	7.40E+04	5.01E+04	3.49E+05
31	15.5	6.16E+04	5.03E+04	3.74E+05
32	16	5.12E+04	5.06E+04	3.99E+05
33	16.5	4.26E+04	5.07E+04	4.24E+05
34	17	3.54E+04	5.09E+04	4.50E+05
35	17.5	2.95E+04	5.10E+04	4.75E+05
36	18	2.45E+04	4.41E+04	4.99E+05
37	18.5	2.04E+04	3.66E+04	5.19E+05
38	19	1.69E+04	3.05E+04	5.36E+05
39	19.5	1.41E+04	2.53E+04	5.50E+05
40	20	1.17E+04	2.11E+04	5.62E+05
41	20.5	9.75E+03	1.75E+04	5.71E+05
42	21	8.11E+03	1.46E+04	5.79E+05
43	21.5	6.74E+03	1.21E+04	5.86E+05
44	22	5.61E+03	1.01E+04	5.92E+05
45	22.5	4.66E+03	8.38E+03	5.96E+05
46	23	3.88E+03	6.97E+03	6.00E+05
47	23.5	3.22E+03	5.80E+03	6.03E+05
48	24	2.68E+03	4.82E+03	6.06E+05
49	24.5	2.23E+03	4.01E+03	6.08E+05
50	25	1.86E+03	3.34E+03	6.10E+05
51	25.5	1.54E+03	2.77E+03	6.11E+05
52	26	1.28E+03	2.31E+03	6.13E+05
53	26.5	1.07E+03	1.92E+03	6.14E+05
54	27	8.87E+02	1.60E+03	6.15E+05
55	27.5	7.38E+02	1.33E+03	6.15E+05
56	28	6.14E+02	1.10E+03	6.16E+05
57	28.5	5.10E+02	9.18E+02	6.16E+05
58	29	4.25E+02	7.63E+02	6.17E+05
59	29.5	3.53E+02	6.35E+02	6.17E+05
60	30	2.94E+02	5.28E+02	6.18E+05
61	30.5	2.44E+02	4.39E+02	6.18E+05
62	31	2.03E+02	3.65E+02	6.18E+05
63	31.5	1.69E+02	3.04E+02	6.18E+05
64	32	1.40E+02	2.53E+02	6.18E+05
65	32.5	1.17E+02	2.10E+02	6.18E+05
66	33	9.72E+01	1.75E+02	6.18E+05
67	33.5	8.08E+01	1.45E+02	6.19E+05
68	34	6.72E+01	1.21E+02	6.19E+05
69	34.5	5.59E+01	1.00E+02	6.19E+05
70	35	4.65E+01	8.36E+01	6.19E+05
71	35.5	3.87E+01	6.95E+01	6.19E+05
72	36	3.21E+01	5.78E+01	6.19E+05
73	36.5	2.67E+01	4.81E+01	6.19E+05
74	37	2.22E+01	4.00E+01	6.19E+05
75	37.5	1.85E+01	3.33E+01	6.19E+05
76	38	1.54E+01	2.77E+01	6.19E+05
77	38.5	1.28E+01	2.30E+01	6.19E+05
78	39	1.06E+01	1.91E+01	6.19E+05
79	39.5	8.85E+00	1.59E+01	6.19E+05
80	40	7.36E+00	1.32E+01	6.19E+05
81	40.5	6.12E+00	1.10E+01	6.19E+05
82	41	5.09E+00	9.15E+00	6.19E+05
83	41.5	4.23E+00	7.61E+00	6.19E+05
84	42	3.52E+00	6.33E+00	6.19E+05
85	42.5	2.93E+00	5.26E+00	6.19E+05
86	43	2.43E+00	4.38E+00	6.19E+05
87	43.5	2.02E+00	3.64E+00	6.19E+05
88	44	1.68E+00	3.03E+00	6.19E+05
89	44.5	1.40E+00	2.52E+00	6.19E+05
90	45	1.16E+00	2.09E+00	6.19E+05
91	45.5	9.68E-01	1.74E+00	6.19E+05
92	46	8.05E-01	1.45E+00	6.19E+05
93	46.5	6.70E-01	1.20E+00	6.19E+05
94	47	5.57E-01	1.00E+00	6.19E+05
95	47.5	4.63E-01	8.33E-01	6.19E+05
96	48	3.85E-01	6.93E-01	6.19E+05
97	48.5	3.20E-01	5.76E-01	6.19E+05
98	49	2.66E-01	4.79E-01	6.19E+05
99	49.5	2.22E-01	3.99E-01	6.19E+05
100	50	1.84E-01	3.31E-01	6.19E+05





Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	38

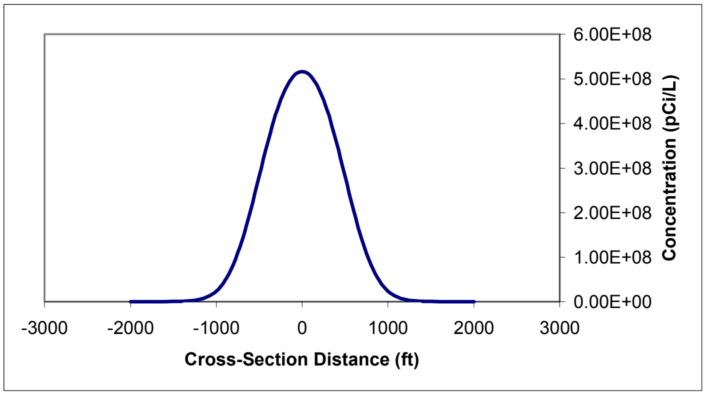


550	0
550	1.00E+08

	x (ft)	C(x;y,t)
0	0	4.23E+06
1	75	5.18E+06
2	150	6.34E+06
3	225	7.61E+06
4	300	9.09E+06
5	375	1.08E+07
6	450	1.27E+07
7	525	1.49E+07
8	600	1.73E+07
9	675	2.01E+07
10	750	2.32E+07
11	825	2.66E+07
12	900	3.04E+07
13	975	3.47E+07
14	1050	3.94E+07
15	1125	4.46E+07
16	1200	5.02E+07
17	1275	5.63E+07
18	1350	6.30E+07
19	1425	7.01E+07
20	1500	7.77E+07
21	1575	8.58E+07
22	1650	9.44E+07
23	1725	1.03E+08
24	1800	1.13E+08
25	1875	1.23E+08
26	1950	1.33E+08
27	2025	1.43E+08
28	2100	1.54E+08
29	2175	1.64E+08
30	2250	1.75E+08
31	2325	1.86E+08
32	2400	1.97E+08
33	2475	2.07E+08
34	2550	2.17E+08
35	2625	2.27E+08
36	2700	2.36E+08
37	2775	2.45E+08
38	2850	2.53E+08
39	2925	2.61E+08
40	3000	2.67E+08

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2000
t (yr) =	30

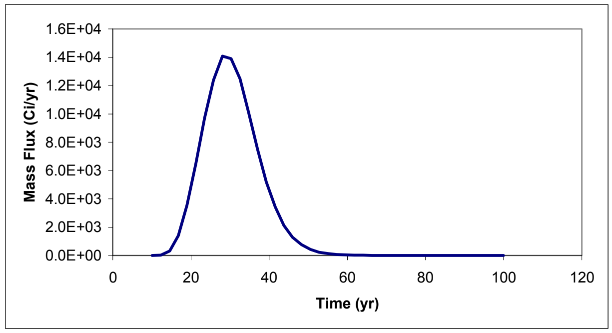


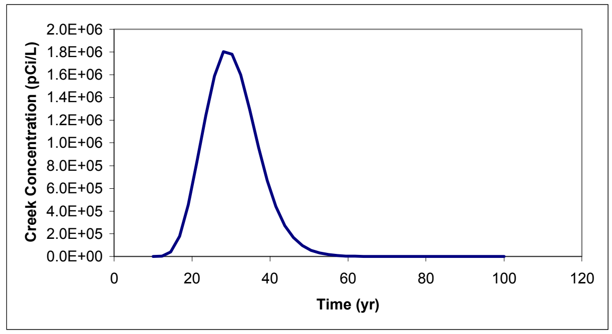
	y (ft)	C(x,y,t)
0	-2000	5.38E+02
1	-1900	2.11E+03
2	-1800	7.79E+03
3	-1700	2.69E+04
4	-1600	8.73E+04
5	-1500	2.65E+05
6	-1400	7.54E+05
7	-1300	2.00E+06
8	-1200	4.95E+06
9	-1100	1.13E+07
10	-1000	2.40E+07
11	-900	4.67E+07
12	-800	8.35E+07
13	-700	1.37E+08
14	-600	2.05E+08
15	-500	2.82E+08
16	-400	3.59E+08
17	-300	4.26E+08
18	-200	4.76E+08
19	-100	5.06E+08
20	0	5.16E+08
21	100	5.06E+08
22	200	4.76E+08
23	300	4.26E+08
24	400	3.59E+08
25	500	2.82E+08
26	600	2.05E+08
27	700	1.37E+08
28	800	8.35E+07
29	900	4.67E+07
30	1000	2.40E+07
31	1100	1.13E+07
32	1200	4.95E+06
33	1300	2.00E+06
34	1400	7.54E+05
35	1500	2.65E+05
36	1600	8.73E+04
37	1700	2.69E+04
38	1800	7.79E+03
39	1900	2.11E+03
40	2000	5.38E+02

Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	1200
t_{min} (yr) =	10
t_{max} (yr) =	100

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	10	2.04E-01	0.00E+00	2.61E+01
1	12.25	2.72E+01	3.08E+01	3.48E+03
2	14.5	3.24E+02	4.25E+02	4.15E+04
3	16.75	1.40E+03	2.36E+03	1.79E+05
4	19	3.55E+03	7.93E+03	4.55E+05
5	21.25	6.50E+03	1.92E+04	8.33E+05
6	23.5	9.69E+03	3.74E+04	1.24E+06
7	25.75	1.24E+04	6.23E+04	1.59E+06
8	28	1.41E+04	9.21E+04	1.80E+06
9	30.25	1.39E+04	1.24E+05	1.78E+06
10	32.5	1.25E+04	1.53E+05	1.60E+06
11	34.75	1.01E+04	1.79E+05	1.29E+06
12	37	7.47E+03	1.98E+05	9.58E+05
13	39.25	5.21E+03	2.13E+05	6.68E+05
14	41.5	3.43E+03	2.22E+05	4.39E+05
15	43.75	2.11E+03	2.29E+05	2.71E+05
16	46	1.30E+03	2.32E+05	1.67E+05
17	48.25	7.59E+02	2.35E+05	9.74E+04
18	50.5	4.33E+02	2.36E+05	5.55E+04
19	52.75	2.39E+02	2.37E+05	3.07E+04
20	55	1.30E+02	2.37E+05	1.67E+04
21	57.25	7.03E+01	2.37E+05	9.02E+03
22	59.5	3.70E+01	2.38E+05	4.75E+03
23	61.75	1.93E+01	2.38E+05	2.47E+03
24	64	9.93E+00	2.38E+05	1.27E+03
25	66.25	5.07E+00	2.38E+05	6.49E+02
26	68.5	2.56E+00	2.38E+05	3.28E+02
27	70.75	1.28E+00	2.38E+05	1.64E+02
28	73	6.37E-01	2.38E+05	8.16E+01
29	75.25	3.16E-01	2.38E+05	4.05E+01
30	77.5	1.55E-01	2.38E+05	1.98E+01
31	79.75	7.58E-02	2.38E+05	9.72E+00
32	82	3.67E-02	2.38E+05	4.70E+00
33	84.25	1.77E-02	2.38E+05	2.27E+00
34	86.5	8.45E-03	2.38E+05	1.08E+00
35	88.75	4.11E-03	2.38E+05	5.26E-01
36	91	1.97E-03	2.38E+05	2.52E-01
37	93.25	9.71E-04	2.38E+05	1.25E-01
38	95.5	4.43E-04	2.38E+05	5.67E-02
39	97.75	2.10E-04	2.38E+05	2.69E-02
40	100	9.94E-05	2.38E+05	1.27E-02





Cs^{137}

Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	5.87E+04	λ_D (yr^{-1})	0.0231
Δt_R (yr)	1	I_m (Ci/yr)	3352
Δt_O (yr)	18		
$T_{1/2}$ (yr)	3.00E+01		

Summary

Total Flux to Water Table (Ci) =	1.13E-03
Total Flux to Creek (Ci) =	1.71E-11
Maximum Flux to Water Table (Ci/yr) =	2.14E-05
Maximum Flux to Creek (Ci/yr) =	6.48E-14
Maximum Creek Concentration (pCi/L) =	8.31E-12

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.0032216
f_L	1.00	I_{max} (Ci)	47002
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^w (L/kg)	15		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	677.6
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	97
n	0.25	D_{xx}' (ft^2/yr)	222.68041
a_L (ft)	135	D_{yy}' (ft^2/yr)	28
a_T (ft)	17	v_x' (ft/yr)	1.649
L (ft)	1000	c_o/M (ft^{-3})	1.34E-10
W (ft)	3500		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	15		

Creek Discharge

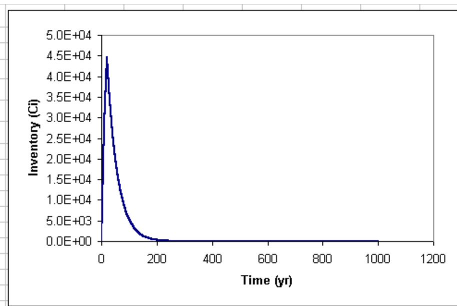
Q_c (m^3/yr)	7.80E+06

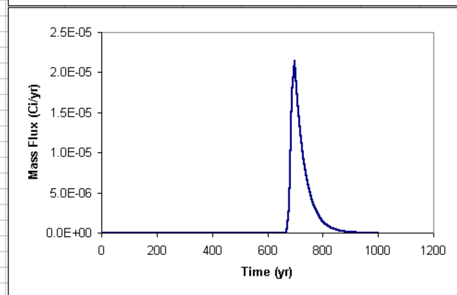
Integral Convergence Criteria

ε_1	0.01	**Local Concentration**
ε_2	0.1	**Creek Flux**

Inventory and Water Table Flux

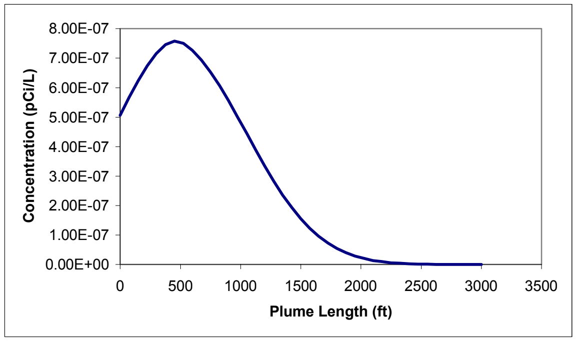
	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	1000		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	10	2.82E+04	0.00E+00	0.00E+00
2	20	4.46E+04	0.00E+00	0.00E+00
3	30	3.43E+04	0.00E+00	0.00E+00
4	40	2.63E+04	0.00E+00	0.00E+00
5	50	2.02E+04	0.00E+00	0.00E+00
6	60	1.56E+04	0.00E+00	0.00E+00
7	70	1.20E+04	0.00E+00	0.00E+00
8	80	9.19E+03	0.00E+00	0.00E+00
9	90	7.06E+03	0.00E+00	0.00E+00
10	100	5.43E+03	0.00E+00	0.00E+00
11	110	4.17E+03	0.00E+00	0.00E+00
12	120	3.21E+03	0.00E+00	0.00E+00
13	130	2.46E+03	0.00E+00	0.00E+00
14	140	1.89E+03	0.00E+00	0.00E+00
15	150	1.46E+03	0.00E+00	0.00E+00
16	160	1.12E+03	0.00E+00	0.00E+00
17	170	8.59E+02	0.00E+00	0.00E+00
18	180	6.61E+02	0.00E+00	0.00E+00
19	190	5.08E+02	0.00E+00	0.00E+00
20	200	3.90E+02	0.00E+00	0.00E+00
21	210	3.00E+02	0.00E+00	0.00E+00
22	220	2.30E+02	0.00E+00	0.00E+00
23	230	1.77E+02	0.00E+00	0.00E+00
24	240	1.36E+02	0.00E+00	0.00E+00
25	250	1.05E+02	0.00E+00	0.00E+00
26	260	8.04E+01	0.00E+00	0.00E+00
27	270	6.18E+01	0.00E+00	0.00E+00
28	280	4.75E+01	0.00E+00	0.00E+00
29	290	3.65E+01	0.00E+00	0.00E+00
30	300	2.80E+01	0.00E+00	0.00E+00
31	310	2.16E+01	0.00E+00	0.00E+00
32	320	1.66E+01	0.00E+00	0.00E+00
33	330	1.27E+01	0.00E+00	0.00E+00
34	340	9.78E+00	0.00E+00	0.00E+00
35	350	7.52E+00	0.00E+00	0.00E+00
36	360	5.78E+00	0.00E+00	0.00E+00
37	370	4.44E+00	0.00E+00	0.00E+00
38	380	3.41E+00	0.00E+00	0.00E+00
39	390	2.62E+00	0.00E+00	0.00E+00
40	400	2.02E+00	0.00E+00	0.00E+00
41	410	1.55E+00	0.00E+00	0.00E+00
42	420	1.19E+00	0.00E+00	0.00E+00
43	430	9.15E-01	0.00E+00	0.00E+00
44	440	7.03E-01	0.00E+00	0.00E+00
45	450	5.41E-01	0.00E+00	0.00E+00
46	460	4.15E-01	0.00E+00	0.00E+00
47	470	3.19E-01	0.00E+00	0.00E+00
48	480	2.45E-01	0.00E+00	0.00E+00
49	490	1.89E-01	0.00E+00	0.00E+00
50	500	1.45E-01	0.00E+00	0.00E+00
51	510	1.11E-01	0.00E+00	0.00E+00
52	520	8.56E-02	0.00E+00	0.00E+00
53	530	6.58E-02	0.00E+00	0.00E+00
54	540	5.06E-02	0.00E+00	0.00E+00
55	550	3.89E-02	0.00E+00	0.00E+00
56	560	2.99E-02	0.00E+00	0.00E+00
57	570	2.30E-02	0.00E+00	0.00E+00
58	580	1.76E-02	0.00E+00	0.00E+00
59	590	1.36E-02	0.00E+00	0.00E+00
60	600	1.04E-02	0.00E+00	0.00E+00
61	610	8.01E-03	0.00E+00	0.00E+00
62	620	6.15E-03	0.00E+00	0.00E+00
63	630	4.73E-03	0.00E+00	0.00E+00
64	640	3.63E-03	0.00E+00	0.00E+00
65	650	2.79E-03	0.00E+00	0.00E+00
66	660	2.15E-03	0.00E+00	0.00E+00
67	670	1.65E-03	0.00E+00	0.00E+00
68	680	1.27E-03	3.18E-06	1.59E-05
69	690	9.75E-04	1.75E-05	1.19E-04
70	700	7.49E-04	2.14E-05	3.14E-04
71	710	5.76E-04	1.65E-05	5.03E-04
72	720	4.42E-04	1.26E-05	6.49E-04
73	730	3.40E-04	9.72E-06	7.61E-04
74	740	2.61E-04	7.47E-06	8.47E-04
75	750	2.01E-04	5.74E-06	9.13E-04
76	760	1.54E-04	4.41E-06	9.63E-04
77	770	1.19E-04	3.39E-06	1.00E-03
78	780	9.12E-05	2.61E-06	1.03E-03
79	790	7.01E-05	2.00E-06	1.06E-03
80	800	5.38E-05	1.54E-06	1.07E-03
81	810	4.14E-05	1.18E-06	1.09E-03
82	820	3.18E-05	9.09E-07	1.10E-03
83	830	2.44E-05	6.99E-07	1.11E-03
84	840	1.88E-05	5.37E-07	1.11E-03
85	850	1.44E-05	4.13E-07	1.12E-03
86	860	1.11E-05	3.17E-07	1.12E-03
87	870	8.53E-06	2.44E-07	1.12E-03
88	880	6.55E-06	1.87E-07	1.12E-03
89	890	5.04E-06	1.44E-07	1.13E-03
90	900	3.87E-06	1.11E-07	1.13E-03
91	910	2.97E-06	8.50E-08	1.13E-03
92	920	2.29E-06	6.54E-08	1.13E-03
93	930	1.76E-06	5.02E-08	1.13E-03
94	940	1.35E-06	3.86E-08	1.13E-03
95	950	1.04E-06	2.97E-08	1.13E-03
96	960	7.98E-07	2.28E-08	1.13E-03
97	970	6.13E-07	1.75E-08	1.13E-03
98	980	4.71E-07	1.35E-08	1.13E-03
99	990	3.62E-07	1.03E-08	1.13E-03
100	1000	2.78E-07	7.95E-09	1.13E-03





Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	1200

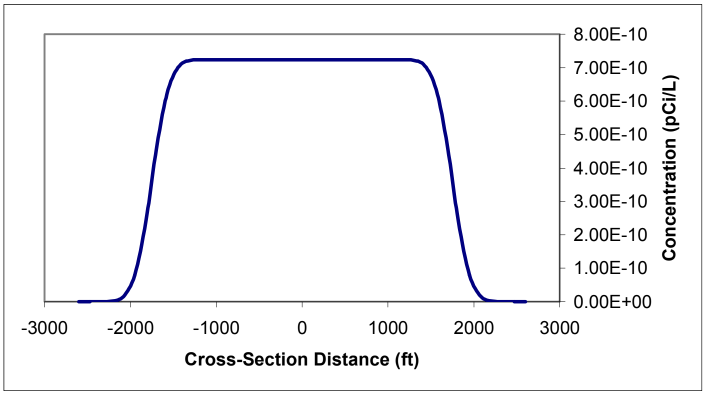


500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	5.06E-07
1	75	5.67E-07
2	150	6.24E-07
3	225	6.75E-07
4	300	7.16E-07
5	375	7.46E-07
6	450	7.58E-07
7	525	7.50E-07
8	600	7.27E-07
9	675	6.94E-07
10	750	6.54E-07
11	825	6.07E-07
12	900	5.56E-07
13	975	5.01E-07
14	1050	4.45E-07
15	1125	3.89E-07
16	1200	3.35E-07
17	1275	2.84E-07
18	1350	2.36E-07
19	1425	1.93E-07
20	1500	1.56E-07
21	1575	1.23E-07
22	1650	9.56E-08
23	1725	7.29E-08
24	1800	5.46E-08
25	1875	4.01E-08
26	1950	2.89E-08
27	2025	2.04E-08
28	2100	1.41E-08
29	2175	9.60E-09
30	2250	6.38E-09
31	2325	4.16E-09
32	2400	2.66E-09
33	2475	1.66E-09
34	2550	1.02E-09
35	2625	6.09E-10
36	2700	3.57E-10
37	2775	2.05E-10
38	2850	1.15E-10
39	2925	6.32E-11
40	3000	3.40E-11

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	1200

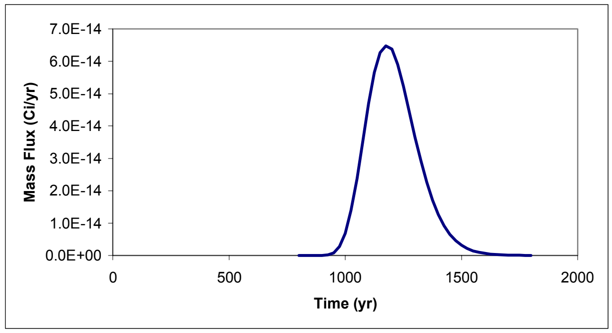


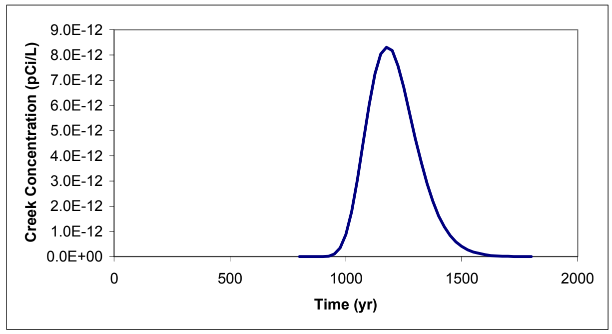
	y (ft)	C(x,y,t)
0	-2600	9.62E-17
1	-2470	4.51E-15
2	-2340	1.20E-13
3	-2210	1.82E-12
4	-2080	1.58E-11
5	-1950	8.00E-11
6	-1820	2.42E-10
7	-1690	4.66E-10
8	-1560	6.35E-10
9	-1430	7.06E-10
10	-1300	7.22E-10
11	-1170	7.24E-10
12	-1040	7.24E-10
13	-910	7.24E-10
14	-780	7.24E-10
15	-650	7.24E-10
16	-520	7.24E-10
17	-390	7.24E-10
18	-260	7.24E-10
19	-130	7.24E-10
20	0	7.24E-10
21	130	7.24E-10
22	260	7.24E-10
23	390	7.24E-10
24	520	7.24E-10
25	650	7.24E-10
26	780	7.24E-10
27	910	7.24E-10
28	1040	7.24E-10
29	1170	7.24E-10
30	1300	7.22E-10
31	1430	7.06E-10
32	1560	6.35E-10
33	1690	4.66E-10
34	1820	2.42E-10
35	1950	8.00E-11
36	2080	1.58E-11
37	2210	1.82E-12
38	2340	1.20E-13
39	2470	4.51E-15
40	2600	9.62E-17

Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	800
t_{max} (yr) =	1800

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	800	1.66E-25	0.00E+00	2.13E-23
1	825	3.11E-22	3.89E-21	3.99E-20
2	850	4.38E-20	5.55E-19	5.61E-18
3	875	1.57E-18	2.07E-17	2.01E-16
4	900	2.27E-17	3.25E-16	2.92E-15
5	925	1.73E-16	2.77E-15	2.22E-14
6	950	8.15E-16	1.51E-14	1.05E-13
7	975	2.71E-15	5.91E-14	3.47E-13
8	1000	6.82E-15	1.78E-13	8.74E-13
9	1025	1.39E-14	4.37E-13	1.78E-12
10	1050	2.38E-14	9.08E-13	3.05E-12
11	1075	3.53E-14	1.65E-12	4.52E-12
12	1100	4.70E-14	2.67E-12	6.03E-12
13	1125	5.65E-14	3.97E-12	7.25E-12
14	1150	6.28E-14	5.46E-12	8.05E-12
15	1175	6.48E-14	7.05E-12	8.31E-12
16	1200	6.38E-14	8.66E-12	8.18E-12
17	1225	5.91E-14	1.02E-11	7.58E-12
18	1250	5.24E-14	1.16E-11	6.71E-12
19	1275	4.45E-14	1.28E-11	5.71E-12
20	1300	3.66E-14	1.38E-11	4.69E-12
21	1325	2.91E-14	1.46E-11	3.74E-12
22	1350	2.26E-14	1.53E-11	2.90E-12
23	1375	1.71E-14	1.58E-11	2.19E-12
24	1400	1.27E-14	1.62E-11	1.63E-12
25	1425	9.20E-15	1.64E-11	1.18E-12
26	1450	6.56E-15	1.66E-11	8.41E-13
27	1475	4.59E-15	1.68E-11	5.88E-13
28	1500	3.16E-15	1.69E-11	4.05E-13
29	1525	2.14E-15	1.69E-11	2.75E-13
30	1550	1.44E-15	1.70E-11	1.85E-13
31	1575	9.58E-16	1.70E-11	1.23E-13
32	1600	6.30E-16	1.70E-11	8.07E-14
33	1625	4.08E-16	1.70E-11	5.23E-14
34	1650	2.62E-16	1.70E-11	3.36E-14
35	1675	1.67E-16	1.70E-11	2.14E-14
36	1700	1.06E-16	1.71E-11	1.36E-14
37	1725	6.65E-17	1.71E-11	8.52E-15
38	1750	4.14E-17	1.71E-11	5.31E-15
39	1775	2.57E-17	1.71E-11	3.29E-15
40	1800	1.58E-17	1.71E-11	2.02E-15





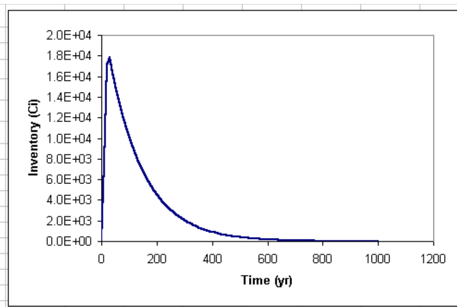
Pu^{238}

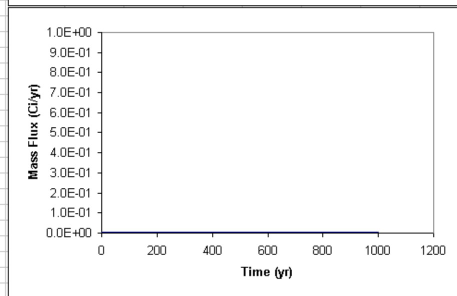
Groundwater Transport - SRS ORWBG

	B	C	D	E	G–J	K
4	***Delivered Inventory and Nulide Decay***				***Summary***	
5	**I_o (Ci)**	**2.05E+04**	λ_D (yr^{-1})	0.0079	**Total Flux to Water Table (Ci) =**	**0.00E+00**
6	**Δt_R (yr)**	**5**	I_m (Ci/yr)	1052	**Total Flux to Creek (Ci) =**	**0.00E+00**
7	**Δt_O (yr)**	**22**			**Maximum Flux to Water Table (Ci/yr) =**	**0.00E+00**
8	**$T_{1/2}$ (yr)**	**8.77E+01**			**Maximum Flux to Creek (Ci/yr) =**	**0.00E+00**
9					**Maximum Creek Concentration (pCi/L) =**	**0.00E+00**
10	***Leaching***					
11	**q_f (ft/yr)**	**1.25**	λ_L (yr^{-1})	8.875E-05		
12	**f_L**	**1.00**	I_{max} (Ci)	18988		
13	**θ_{waste}**	**0.25**				
14	**ρ_{waste} (kg/L)**	**1.6**				
15	**K_d^w (L/kg)**	**550**				
16	**L_{waste} (ft)**	**16**				
18	***Vadose Zone***					
19	**L_{vz} (ft)**	**35**	Δt_{vz} (yr)	24645.6		
20	**θ_{vz}**	**0.2**				
22	***Aquifer Parameters***					
23	**q_x (ft/yr)**	**40**	R	3521		
24	**n**	**0.25**	D_{xx}' (ft^2/yr)	6.1346208		
25	**a_L (ft)**	**135**	D_{yy}' (ft^2/yr)	1		
26	**a_T (ft)**	**17**	v_x' (ft/yr)	0.045		
27	**L (ft)**	**1000**	c_o/M (ft^{-3})	3.69E-12		
28	**W (ft)**	**3500**				
29	**H (ft)**	**22**				
30	**ρ_b (kg/L)**	**1.6**				
31	**K_d (L/kg)**	**550**				
33	***Creek Discharge***					
34	**Q_c (m^3/yr)**	**7.80E+06**				
36	***Integral Convergence Criteria***					
37	**ε_1**	**0.01**	**Local Concentration**			
38	**ε_2**	**0.1**	**Creek Flux**			

Inventory and Water Table Flux

	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	1000		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	10	7.65E+03	0.00E+00	0.00E+00
2	20	1.72E+04	0.00E+00	0.00E+00
3	30	1.78E+04	0.00E+00	0.00E+00
4	40	1.64E+04	0.00E+00	0.00E+00
5	50	1.52E+04	0.00E+00	0.00E+00
6	60	1.40E+04	0.00E+00	0.00E+00
7	70	1.29E+04	0.00E+00	0.00E+00
8	80	1.19E+04	0.00E+00	0.00E+00
9	90	1.10E+04	0.00E+00	0.00E+00
10	100	1.02E+04	0.00E+00	0.00E+00
11	110	9.40E+03	0.00E+00	0.00E+00
12	120	8.68E+03	0.00E+00	0.00E+00
13	130	8.01E+03	0.00E+00	0.00E+00
14	140	7.39E+03	0.00E+00	0.00E+00
15	150	6.83E+03	0.00E+00	0.00E+00
16	160	6.30E+03	0.00E+00	0.00E+00
17	170	5.82E+03	0.00E+00	0.00E+00
18	180	5.37E+03	0.00E+00	0.00E+00
19	190	4.96E+03	0.00E+00	0.00E+00
20	200	4.58E+03	0.00E+00	0.00E+00
21	210	4.23E+03	0.00E+00	0.00E+00
22	220	3.90E+03	0.00E+00	0.00E+00
23	230	3.60E+03	0.00E+00	0.00E+00
24	240	3.32E+03	0.00E+00	0.00E+00
25	250	3.07E+03	0.00E+00	0.00E+00
26	260	2.83E+03	0.00E+00	0.00E+00
27	270	2.62E+03	0.00E+00	0.00E+00
28	280	2.42E+03	0.00E+00	0.00E+00
29	290	2.23E+03	0.00E+00	0.00E+00
30	300	2.06E+03	0.00E+00	0.00E+00
31	310	1.90E+03	0.00E+00	0.00E+00
32	320	1.75E+03	0.00E+00	0.00E+00
33	330	1.62E+03	0.00E+00	0.00E+00
34	340	1.50E+03	0.00E+00	0.00E+00
35	350	1.38E+03	0.00E+00	0.00E+00
36	360	1.27E+03	0.00E+00	0.00E+00
37	370	1.18E+03	0.00E+00	0.00E+00
38	380	1.09E+03	0.00E+00	0.00E+00
39	390	1.00E+03	0.00E+00	0.00E+00
40	400	9.26E+02	0.00E+00	0.00E+00
41	410	8.54E+02	0.00E+00	0.00E+00
42	420	7.89E+02	0.00E+00	0.00E+00
43	430	7.28E+02	0.00E+00	0.00E+00
44	440	6.72E+02	0.00E+00	0.00E+00
45	450	6.21E+02	0.00E+00	0.00E+00
46	460	5.73E+02	0.00E+00	0.00E+00
47	470	5.29E+02	0.00E+00	0.00E+00
48	480	4.88E+02	0.00E+00	0.00E+00
49	490	4.51E+02	0.00E+00	0.00E+00
50	500	4.16E+02	0.00E+00	0.00E+00
51	510	3.84E+02	0.00E+00	0.00E+00
52	520	3.55E+02	0.00E+00	0.00E+00
53	530	3.27E+02	0.00E+00	0.00E+00
54	540	3.02E+02	0.00E+00	0.00E+00
55	550	2.79E+02	0.00E+00	0.00E+00
56	560	2.58E+02	0.00E+00	0.00E+00
57	570	2.38E+02	0.00E+00	0.00E+00
58	580	2.20E+02	0.00E+00	0.00E+00
59	590	2.03E+02	0.00E+00	0.00E+00
60	600	1.87E+02	0.00E+00	0.00E+00
61	610	1.73E+02	0.00E+00	0.00E+00
62	620	1.60E+02	0.00E+00	0.00E+00
63	630	1.47E+02	0.00E+00	0.00E+00
64	640	1.36E+02	0.00E+00	0.00E+00
65	650	1.26E+02	0.00E+00	0.00E+00
66	660	1.16E+02	0.00E+00	0.00E+00
67	670	1.07E+02	0.00E+00	0.00E+00
68	680	9.87E+01	0.00E+00	0.00E+00
69	690	9.12E+01	0.00E+00	0.00E+00
70	700	8.42E+01	0.00E+00	0.00E+00
71	710	7.77E+01	0.00E+00	0.00E+00
72	720	7.17E+01	0.00E+00	0.00E+00
73	730	6.62E+01	0.00E+00	0.00E+00
74	740	6.11E+01	0.00E+00	0.00E+00
75	750	5.64E+01	0.00E+00	0.00E+00
76	760	5.21E+01	0.00E+00	0.00E+00
77	770	4.81E+01	0.00E+00	0.00E+00
78	780	4.44E+01	0.00E+00	0.00E+00
79	790	4.10E+01	0.00E+00	0.00E+00
80	800	3.78E+01	0.00E+00	0.00E+00
81	810	3.49E+01	0.00E+00	0.00E+00
82	820	3.23E+01	0.00E+00	0.00E+00
83	830	2.98E+01	0.00E+00	0.00E+00
84	840	2.75E+01	0.00E+00	0.00E+00
85	850	2.54E+01	0.00E+00	0.00E+00
86	860	2.34E+01	0.00E+00	0.00E+00
87	870	2.16E+01	0.00E+00	0.00E+00
88	880	2.00E+01	0.00E+00	0.00E+00
89	890	1.84E+01	0.00E+00	0.00E+00
90	900	1.70E+01	0.00E+00	0.00E+00
91	910	1.57E+01	0.00E+00	0.00E+00
92	920	1.45E+01	0.00E+00	0.00E+00
93	930	1.34E+01	0.00E+00	0.00E+00
94	940	1.24E+01	0.00E+00	0.00E+00
95	950	1.14E+01	0.00E+00	0.00E+00
96	960	1.05E+01	0.00E+00	0.00E+00
97	970	9.73E+00	0.00E+00	0.00E+00
98	980	8.98E+00	0.00E+00	0.00E+00
99	990	8.29E+00	0.00E+00	0.00E+00
100	1000	7.65E+00	0.00E+00	0.00E+00

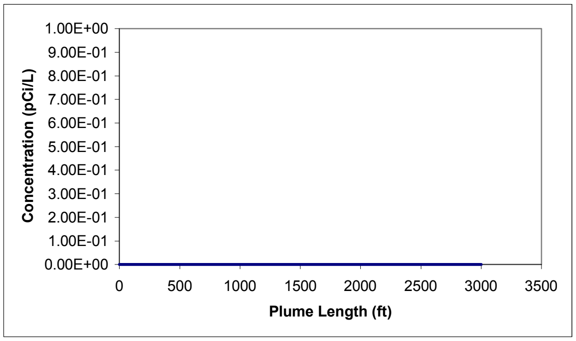




Plume Profile

x_{min} (ft) =	**0**
x_{max} (ft) =	**3000**
y (ft) =	**0**
t (yr) =	**1000**

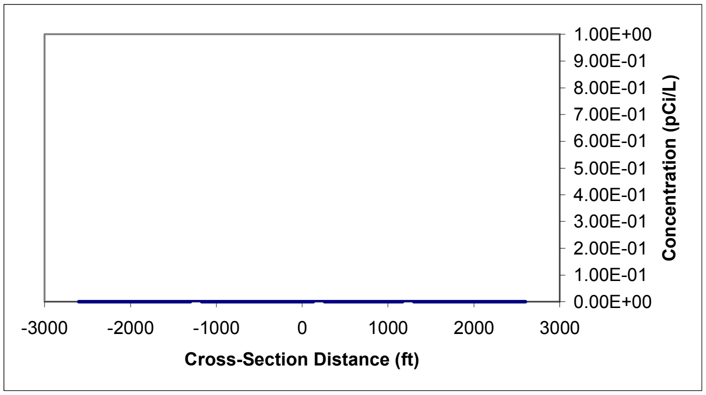
	x (ft)	C(x;y,t)
0	0	0.00E+00
1	75	0.00E+00
2	150	0.00E+00
3	225	0.00E+00
4	300	0.00E+00
5	375	0.00E+00
6	450	0.00E+00
7	525	0.00E+00
8	600	0.00E+00
9	675	0.00E+00
10	750	0.00E+00
11	825	0.00E+00
12	900	0.00E+00
13	975	0.00E+00
14	1050	0.00E+00
15	1125	0.00E+00
16	1200	0.00E+00
17	1275	0.00E+00
18	1350	0.00E+00
19	1425	0.00E+00
20	1500	0.00E+00
21	1575	0.00E+00
22	1650	0.00E+00
23	1725	0.00E+00
24	1800	0.00E+00
25	1875	0.00E+00
26	1950	0.00E+00
27	2025	0.00E+00
28	2100	0.00E+00
29	2175	0.00E+00
30	2250	0.00E+00
31	2325	0.00E+00
32	2400	0.00E+00
33	2475	0.00E+00
34	2550	0.00E+00
35	2625	0.00E+00
36	2700	0.00E+00
37	2775	0.00E+00
38	2850	0.00E+00
39	2925	0.00E+00
40	3000	0.00E+00



500	0
500	1.00E+08

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	1000

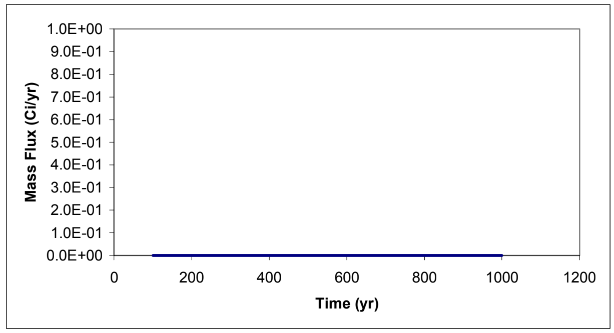


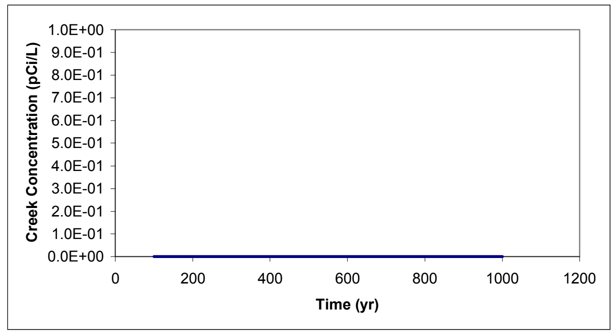
	y (ft)	C(x,y,t)
0	-2600	0.00E+00
1	-2470	0.00E+00
2	-2340	0.00E+00
3	-2210	0.00E+00
4	-2080	0.00E+00
5	-1950	0.00E+00
6	-1820	0.00E+00
7	-1690	0.00E+00
8	-1560	0.00E+00
9	-1430	0.00E+00
10	-1300	0.00E+00
11	-1170	0.00E+00
12	-1040	0.00E+00
13	-910	0.00E+00
14	-780	0.00E+00
15	-650	0.00E+00
16	-520	0.00E+00
17	-390	0.00E+00
18	-260	0.00E+00
19	-130	0.00E+00
20	0	0.00E+00
21	130	0.00E+00
22	260	0.00E+00
23	390	0.00E+00
24	520	0.00E+00
25	650	0.00E+00
26	780	0.00E+00
27	910	0.00E+00
28	1040	0.00E+00
29	1170	0.00E+00
30	1300	0.00E+00
31	1430	0.00E+00
32	1560	0.00E+00
33	1690	0.00E+00
34	1820	0.00E+00
35	1950	0.00E+00
36	2080	0.00E+00
37	2210	0.00E+00
38	2340	0.00E+00
39	2470	0.00E+00
40	2600	0.00E+00

Creek Flux and Concentration

X_c (ft) =	**2600**
y_{max} (ft) =	**2600**
t_{min} (yr) =	**100**
t_{max} (yr) =	**1000**

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	100	0.00E+00	0.00E+00	0.00E+00
1	122.5	0.00E+00	0.00E+00	0.00E+00
2	145	0.00E+00	0.00E+00	0.00E+00
3	167.5	0.00E+00	0.00E+00	0.00E+00
4	190	0.00E+00	0.00E+00	0.00E+00
5	212.5	0.00E+00	0.00E+00	0.00E+00
6	235	0.00E+00	0.00E+00	0.00E+00
7	257.5	0.00E+00	0.00E+00	0.00E+00
8	280	0.00E+00	0.00E+00	0.00E+00
9	302.5	0.00E+00	0.00E+00	0.00E+00
10	325	0.00E+00	0.00E+00	0.00E+00
11	347.5	0.00E+00	0.00E+00	0.00E+00
12	370	0.00E+00	0.00E+00	0.00E+00
13	392.5	0.00E+00	0.00E+00	0.00E+00
14	415	0.00E+00	0.00E+00	0.00E+00
15	437.5	0.00E+00	0.00E+00	0.00E+00
16	460	0.00E+00	0.00E+00	0.00E+00
17	482.5	0.00E+00	0.00E+00	0.00E+00
18	505	0.00E+00	0.00E+00	0.00E+00
19	527.5	0.00E+00	0.00E+00	0.00E+00
20	550	0.00E+00	0.00E+00	0.00E+00
21	572.5	0.00E+00	0.00E+00	0.00E+00
22	595	0.00E+00	0.00E+00	0.00E+00
23	617.5	0.00E+00	0.00E+00	0.00E+00
24	640	0.00E+00	0.00E+00	0.00E+00
25	662.5	0.00E+00	0.00E+00	0.00E+00
26	685	0.00E+00	0.00E+00	0.00E+00
27	707.5	0.00E+00	0.00E+00	0.00E+00
28	730	0.00E+00	0.00E+00	0.00E+00
29	752.5	0.00E+00	0.00E+00	0.00E+00
30	775	0.00E+00	0.00E+00	0.00E+00
31	797.5	0.00E+00	0.00E+00	0.00E+00
32	820	0.00E+00	0.00E+00	0.00E+00
33	842.5	0.00E+00	0.00E+00	0.00E+00
34	865	0.00E+00	0.00E+00	0.00E+00
35	887.5	0.00E+00	0.00E+00	0.00E+00
36	910	0.00E+00	0.00E+00	0.00E+00
37	932.5	0.00E+00	0.00E+00	0.00E+00
38	955	0.00E+00	0.00E+00	0.00E+00
39	977.5	0.00E+00	0.00E+00	0.00E+00
40	1000	0.00E+00	0.00E+00	0.00E+00



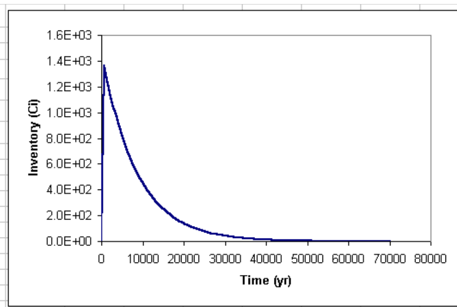


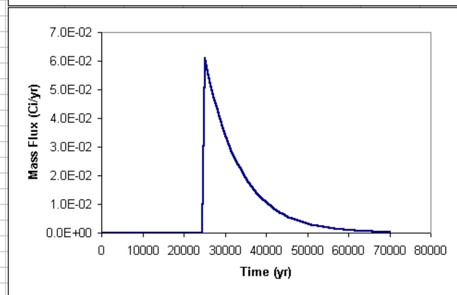
Pu^{239}

	A	B	C	D	E	F	G	H	I	J	K
1											
2		***Groundwater Transport - SRS ORWBG***									
3											
4		***Delivered Inventory and Nulide Decay***					***Summary***				
5		**I_o (Ci)**	**1.48E+03**	λ_D (yr^{-1})	0.0000		**Total Flux to Water Table (Ci) =**				**5.39E+02**
6		**Δt_R (yr)**	**5**	I_m (Ci/yr)	76		**Total Flux to Creek (Ci) =**				**1.07E+02**
7		**Δt_O (yr)**	**22**				**Maximum Flux to Water Table (Ci/yr) =**				**6.09E-02**
8		**$T_{1/2}$ (yr)**	**2.44E+04**				**Maximum Flux to Creek (Ci/yr) =**				**2.41E-03**
9							**Maximum Creek Concentration (pCi/L) =**				**3.10E-01**
10		***Leaching***									
11		**q_f (ft/yr)**	**1.25**	λ_L (yr^{-1})	8.875E-05						
12		**f_L**	**1.00**	I_{max} (Ci)	1473						
13		**θ_{waste}**	**0.25**								
14		**ρ_{waste} (kg/L)**	**1.6**								
15		**K_d^w (L/kg)**	**550**								
16		**L_{waste} (ft)**	**16**								
17											
18		***Vadose Zone***									
19		**L_{vz} (ft)**	**35**	Δt_{vz} (yr)	24645.6						
20		**θ_{vz}**	**0.2**								
21											
22		***Aquifer Parameters***									
23		**q_x (ft/yr)**	**40**	R	3521						
24		**n**	**0.25**	D_{xx}' (ft^2/yr)	6.1346208						
25		**a_L (ft)**	**135**	D_{yy}' (ft^2/yr)	1						
26		**a_T (ft)**	**17**	v_x' (ft/yr)	0.045						
27		**L (ft)**	**1000**	c_o/M (ft^{-3})	3.69E-12						
28		**W (ft)**	**3500**								
29		**H (ft)**	**22**								
30		**ρ_b (kg/L)**	**1.6**								
31		**K_d (L/kg)**	**550**								
32											
33		***Creek Discharge***									
34		**Q_c (m^3/yr)**	**7.80E+06**								
35											
36		***Integral Convergence Criteria***									
37		**ε_1**	**0.01**	**Local Concentration**							
38		**ε_2**	**0.1**	**Creek Flux**							

Inventory and Water Table Flux

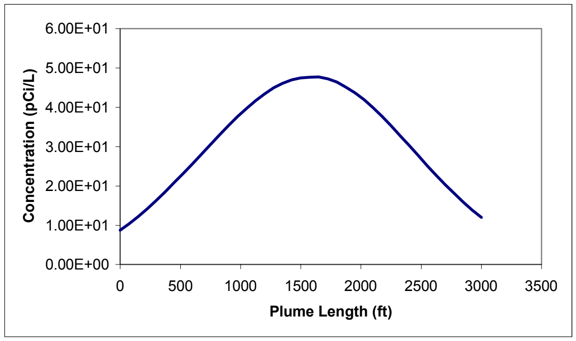
	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	70000		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	700	1.36E+03	0.00E+00	0.00E+00
2	1400	1.25E+03	0.00E+00	0.00E+00
3	2100	1.15E+03	0.00E+00	0.00E+00
4	2800	1.06E+03	0.00E+00	0.00E+00
5	3500	9.80E+02	0.00E+00	0.00E+00
6	4200	9.03E+02	0.00E+00	0.00E+00
7	4900	8.32E+02	0.00E+00	0.00E+00
8	5600	7.66E+02	0.00E+00	0.00E+00
9	6300	7.06E+02	0.00E+00	0.00E+00
10	7000	6.50E+02	0.00E+00	0.00E+00
11	7700	5.99E+02	0.00E+00	0.00E+00
12	8400	5.52E+02	0.00E+00	0.00E+00
13	9100	5.08E+02	0.00E+00	0.00E+00
14	9800	4.68E+02	0.00E+00	0.00E+00
15	10500	4.31E+02	0.00E+00	0.00E+00
16	11200	3.97E+02	0.00E+00	0.00E+00
17	11900	3.66E+02	0.00E+00	0.00E+00
18	12600	3.37E+02	0.00E+00	0.00E+00
19	13300	3.11E+02	0.00E+00	0.00E+00
20	14000	2.86E+02	0.00E+00	0.00E+00
21	14700	2.64E+02	0.00E+00	0.00E+00
22	15400	2.43E+02	0.00E+00	0.00E+00
23	16100	2.24E+02	0.00E+00	0.00E+00
24	16800	2.06E+02	0.00E+00	0.00E+00
25	17500	1.90E+02	0.00E+00	0.00E+00
26	18200	1.75E+02	0.00E+00	0.00E+00
27	18900	1.61E+02	0.00E+00	0.00E+00
28	19600	1.48E+02	0.00E+00	0.00E+00
29	20300	1.37E+02	0.00E+00	0.00E+00
30	21000	1.26E+02	0.00E+00	0.00E+00
31	21700	1.16E+02	0.00E+00	0.00E+00
32	22400	1.07E+02	0.00E+00	0.00E+00
33	23100	9.85E+01	0.00E+00	0.00E+00
34	23800	9.08E+01	0.00E+00	0.00E+00
35	24500	8.36E+01	0.00E+00	0.00E+00
36	25200	7.70E+01	6.09E-02	2.13E+01
37	25900	7.10E+01	5.61E-02	6.23E+01
38	26600	6.54E+01	5.17E-02	1.00E+02
39	27300	6.02E+01	4.76E-02	1.35E+02
40	28000	5.55E+01	4.39E-02	1.67E+02
41	28700	5.11E+01	4.04E-02	1.96E+02
42	29400	4.71E+01	3.72E-02	2.24E+02
43	30100	4.34E+01	3.43E-02	2.49E+02
44	30800	4.00E+01	3.16E-02	2.72E+02
45	31500	3.68E+01	2.91E-02	2.93E+02
46	32200	3.39E+01	2.68E-02	3.12E+02
47	32900	3.12E+01	2.47E-02	3.31E+02
48	33600	2.88E+01	2.28E-02	3.47E+02
49	34300	2.65E+01	2.10E-02	3.62E+02
50	35000	2.44E+01	1.93E-02	3.77E+02
51	35700	2.25E+01	1.78E-02	3.90E+02
52	36400	2.07E+01	1.64E-02	4.01E+02
53	37100	1.91E+01	1.51E-02	4.13E+02
54	37800	1.76E+01	1.39E-02	4.23E+02
55	38500	1.62E+01	1.28E-02	4.32E+02
56	39200	1.49E+01	1.18E-02	4.41E+02
57	39900	1.38E+01	1.09E-02	4.49E+02
58	40600	1.27E+01	1.00E-02	4.56E+02
59	41300	1.17E+01	9.23E-03	4.63E+02
60	42000	1.08E+01	8.50E-03	4.69E+02
61	42700	9.91E+00	7.83E-03	4.75E+02
62	43400	9.13E+00	7.22E-03	4.80E+02
63	44100	8.41E+00	6.65E-03	4.85E+02
64	44800	7.74E+00	6.13E-03	4.89E+02
65	45500	7.13E+00	5.64E-03	4.93E+02
66	46200	6.57E+00	5.20E-03	4.97E+02
67	46900	6.05E+00	4.79E-03	5.01E+02
68	47600	5.58E+00	4.41E-03	5.04E+02
69	48300	5.14E+00	4.06E-03	5.07E+02
70	49000	4.73E+00	3.74E-03	5.09E+02
71	49700	4.36E+00	3.45E-03	5.12E+02
72	50400	4.02E+00	3.18E-03	5.14E+02
73	51100	3.70E+00	2.93E-03	5.16E+02
74	51800	3.41E+00	2.70E-03	5.18E+02
75	52500	3.14E+00	2.48E-03	5.20E+02
76	53200	2.89E+00	2.29E-03	5.22E+02
77	53900	2.67E+00	2.11E-03	5.23E+02
78	54600	2.46E+00	1.94E-03	5.25E+02
79	55300	2.26E+00	1.79E-03	5.26E+02
80	56000	2.08E+00	1.65E-03	5.27E+02
81	56700	1.92E+00	1.52E-03	5.28E+02
82	57400	1.77E+00	1.40E-03	5.30E+02
83	58100	1.63E+00	1.29E-03	5.30E+02
84	58800	1.50E+00	1.19E-03	5.31E+02
85	59500	1.38E+00	1.09E-03	5.32E+02
86	60200	1.27E+00	1.01E-03	5.33E+02
87	60900	1.17E+00	9.28E-04	5.34E+02
88	61600	1.08E+00	8.55E-04	5.34E+02
89	62300	9.96E-01	7.88E-04	5.35E+02
90	63000	9.17E-01	7.26E-04	5.35E+02
91	63700	8.45E-01	6.68E-04	5.36E+02
92	64400	7.79E-01	6.16E-04	5.36E+02
93	65100	7.17E-01	5.67E-04	5.37E+02
94	65800	6.61E-01	5.23E-04	5.37E+02
95	66500	6.09E-01	4.81E-04	5.37E+02
96	67200	5.61E-01	4.44E-04	5.38E+02
97	67900	5.17E-01	4.09E-04	5.38E+02
98	68600	4.76E-01	3.76E-04	5.38E+02
99	69300	4.38E-01	3.47E-04	5.38E+02
100	70000	4.04E-01	3.19E-04	5.39E+02





Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	70000

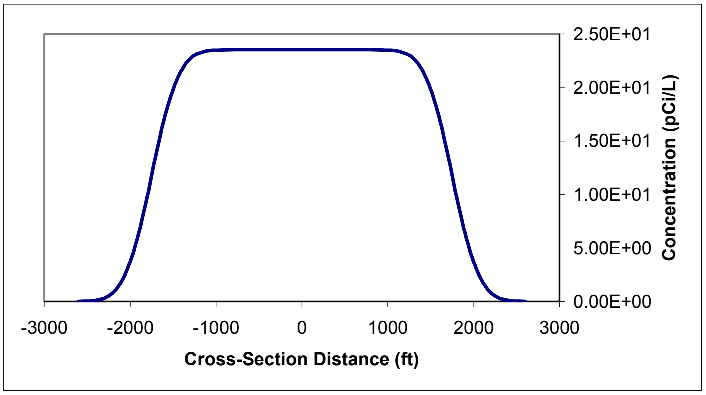


500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	8.72E+00
1	75	1.04E+01
2	150	1.22E+01
3	225	1.42E+01
4	300	1.64E+01
5	375	1.86E+01
6	450	2.09E+01
7	525	2.33E+01
8	600	2.56E+01
9	675	2.80E+01
10	750	3.04E+01
11	825	3.30E+01
12	900	3.54E+01
13	975	3.76E+01
14	1050	3.98E+01
15	1125	4.17E+01
16	1200	4.34E+01
17	1275	4.49E+01
18	1350	4.61E+01
19	1425	4.70E+01
20	1500	4.75E+01
21	1575	4.77E+01
22	1650	4.78E+01
23	1725	4.72E+01
24	1800	4.64E+01
25	1875	4.52E+01
26	1950	4.37E+01
27	2025	4.19E+01
28	2100	3.99E+01
29	2175	3.77E+01
30	2250	3.53E+01
31	2325	3.29E+01
32	2400	3.03E+01
33	2475	2.78E+01
34	2550	2.52E+01
35	2625	2.27E+01
36	2700	2.03E+01
37	2775	1.81E+01
38	2850	1.59E+01
39	2925	1.39E+01
40	3000	1.20E+01

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	70000

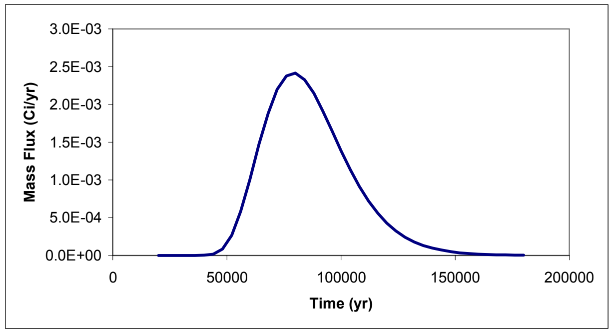


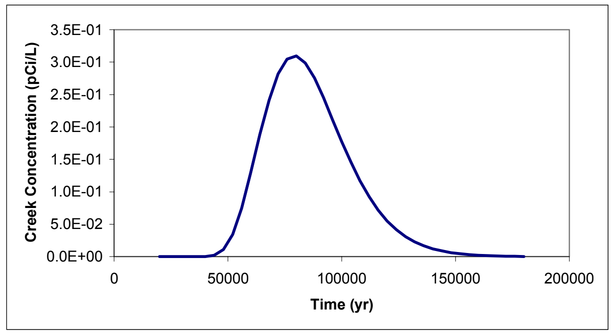
	y (ft)	C(x,y,t)
0	-2600	8.60E-03
1	-2470	4.81E-02
2	-2340	2.15E-01
3	-2210	7.64E-01
4	-2080	2.17E+00
5	-1950	4.96E+00
6	-1820	9.14E+00
7	-1690	1.40E+01
8	-1560	1.83E+01
9	-1430	2.12E+01
10	-1300	2.27E+01
11	-1170	2.33E+01
12	-1040	2.35E+01
13	-910	2.35E+01
14	-780	2.35E+01
15	-650	2.35E+01
16	-520	2.35E+01
17	-390	2.35E+01
18	-260	2.35E+01
19	-130	2.35E+01
20	0	2.35E+01
21	130	2.35E+01
22	260	2.35E+01
23	390	2.35E+01
24	520	2.35E+01
25	650	2.35E+01
26	780	2.35E+01
27	910	2.35E+01
28	1040	2.35E+01
29	1170	2.33E+01
30	1300	2.27E+01
31	1430	2.12E+01
32	1560	1.83E+01
33	1690	1.40E+01
34	1820	9.14E+00
35	1950	4.96E+00
36	2080	2.17E+00
37	2210	7.64E-01
38	2340	2.15E-01
39	2470	4.81E-02
40	2600	8.60E-03

Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	20000
t_{max} (yr) =	180000

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	20000	0.00E+00	0.00E+00	0.00E+00
1	24000	0.00E+00	0.00E+00	0.00E+00
2	28000	0.00E+00	0.00E+00	0.00E+00
3	32000	1.29E-12	2.58E-09	1.65E-10
4	36000	1.42E-08	2.83E-05	1.81E-06
5	40000	1.24E-06	2.54E-03	1.59E-04
6	44000	1.67E-05	3.85E-02	2.15E-03
7	48000	8.76E-05	2.47E-01	1.12E-02
8	52000	2.68E-04	9.58E-01	3.44E-02
9	56000	5.83E-04	2.66E+00	7.48E-02
10	60000	1.01E-03	5.84E+00	1.29E-01
11	64000	1.47E-03	1.08E+01	1.88E-01
12	68000	1.88E-03	1.75E+01	2.41E-01
13	72000	2.20E-03	2.57E+01	2.82E-01
14	76000	2.38E-03	3.48E+01	3.05E-01
15	80000	2.41E-03	4.44E+01	3.10E-01
16	84000	2.33E-03	5.39E+01	2.98E-01
17	88000	2.15E-03	6.28E+01	2.76E-01
18	92000	1.91E-03	7.10E+01	2.45E-01
19	96000	1.65E-03	7.81E+01	2.12E-01
20	100000	1.39E-03	8.42E+01	1.78E-01
21	104000	1.14E-03	8.92E+01	1.46E-01
22	108000	9.13E-04	9.33E+01	1.17E-01
23	112000	7.21E-04	9.66E+01	9.24E-02
24	116000	5.60E-04	9.91E+01	7.18E-02
25	120000	4.29E-04	1.01E+02	5.50E-02
26	124000	3.24E-04	1.03E+02	4.16E-02
27	128000	2.42E-04	1.04E+02	3.11E-02
28	132000	1.79E-04	1.05E+02	2.30E-02
29	136000	1.32E-04	1.05E+02	1.69E-02
30	140000	9.57E-05	1.06E+02	1.23E-02
31	144000	6.90E-05	1.06E+02	8.85E-03
32	148000	4.95E-05	1.06E+02	6.34E-03
33	152000	3.52E-05	1.06E+02	4.52E-03
34	156000	2.49E-05	1.07E+02	3.20E-03
35	160000	1.76E-05	1.07E+02	2.25E-03
36	164000	1.23E-05	1.07E+02	1.58E-03
37	168000	8.55E-06	1.07E+02	1.10E-03
38	172000	5.93E-06	1.07E+02	7.60E-04
39	176000	4.06E-06	1.07E+02	5.21E-04
40	180000	2.80E-06	1.07E+02	3.59E-04





Sr^{90}

Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	5.87E+04	λ_D (yr^{-1})	0.0238
Δt_R (yr)	1	I_m (Ci/yr)	3352
Δt_O (yr)	18		
$T_{1/2}$ (yr)	2.91E+01		

Summary

Total Flux to Water Table (Ci) =	**6.87E-04**
Total Flux to Creek (Ci) =	**7.41E-12**
Maximum Flux to Water Table (Ci/yr) =	**1.32E-05**
Maximum Flux to Creek (Ci/yr) =	**2.87E-14**
Maximum Creek Concentration (pCi/L) =	**3.68E-12**

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.0032216
f_L	1.00	I_{max} (Ci)	46737
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^w (L/kg)	15		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	677.6
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	97
n	0.25	D_{xx}' (ft^2/yr)	222.68041
a_L (ft)	135	D_{yy}' (ft^2/yr)	28
a_T (ft)	17	v_x' (ft/yr)	1.649
L (ft)	1000	c_o/M (ft^{-3})	1.34E-10
W (ft)	3500		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	15		

Creek Discharge

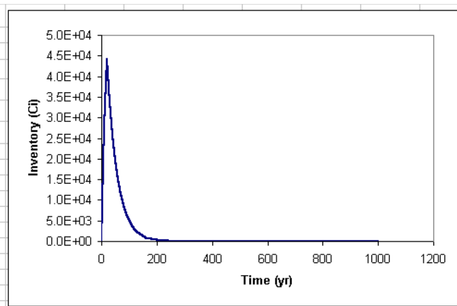
Q_c (m^3/yr)	7.80E+06

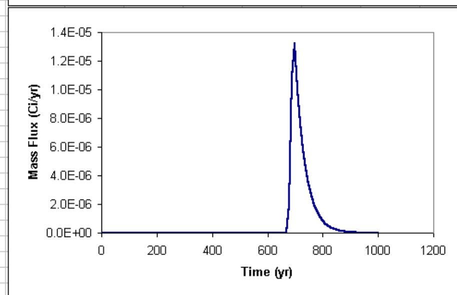
Integral Convergence Criteria

ε_1	0.01	**Local Concentration**
ε_2	0.1	**Creek Flux**

Inventory and Water Table Flux

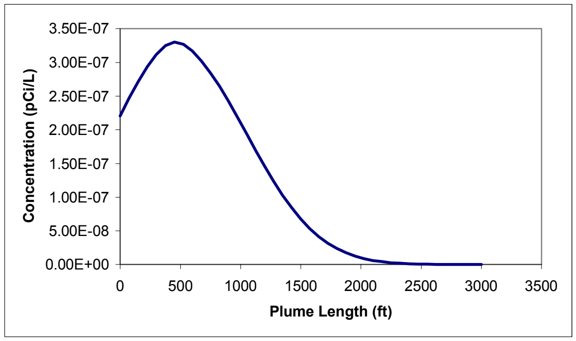
	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	1000		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	10	2.81E+04	0.00E+00	0.00E+00
2	20	4.43E+04	0.00E+00	0.00E+00
3	30	3.38E+04	0.00E+00	0.00E+00
4	40	2.58E+04	0.00E+00	0.00E+00
5	50	1.97E+04	0.00E+00	0.00E+00
6	60	1.50E+04	0.00E+00	0.00E+00
7	70	1.15E+04	0.00E+00	0.00E+00
8	80	8.75E+03	0.00E+00	0.00E+00
9	90	6.68E+03	0.00E+00	0.00E+00
10	100	5.10E+03	0.00E+00	0.00E+00
11	110	3.89E+03	0.00E+00	0.00E+00
12	120	2.97E+03	0.00E+00	0.00E+00
13	130	2.27E+03	0.00E+00	0.00E+00
14	140	1.73E+03	0.00E+00	0.00E+00
15	150	1.32E+03	0.00E+00	0.00E+00
16	160	1.01E+03	0.00E+00	0.00E+00
17	170	7.69E+02	0.00E+00	0.00E+00
18	180	5.87E+02	0.00E+00	0.00E+00
19	190	4.48E+02	0.00E+00	0.00E+00
20	200	3.42E+02	0.00E+00	0.00E+00
21	210	2.61E+02	0.00E+00	0.00E+00
22	220	1.99E+02	0.00E+00	0.00E+00
23	230	1.52E+02	0.00E+00	0.00E+00
24	240	1.16E+02	0.00E+00	0.00E+00
25	250	8.85E+01	0.00E+00	0.00E+00
26	260	6.75E+01	0.00E+00	0.00E+00
27	270	5.15E+01	0.00E+00	0.00E+00
28	280	3.93E+01	0.00E+00	0.00E+00
29	290	3.00E+01	0.00E+00	0.00E+00
30	300	2.29E+01	0.00E+00	0.00E+00
31	310	1.75E+01	0.00E+00	0.00E+00
32	320	1.33E+01	0.00E+00	0.00E+00
33	330	1.02E+01	0.00E+00	0.00E+00
34	340	7.77E+00	0.00E+00	0.00E+00
35	350	5.93E+00	0.00E+00	0.00E+00
36	360	4.53E+00	0.00E+00	0.00E+00
37	370	3.45E+00	0.00E+00	0.00E+00
38	380	2.64E+00	0.00E+00	0.00E+00
39	390	2.01E+00	0.00E+00	0.00E+00
40	400	1.54E+00	0.00E+00	0.00E+00
41	410	1.17E+00	0.00E+00	0.00E+00
42	420	8.94E-01	0.00E+00	0.00E+00
43	430	6.83E-01	0.00E+00	0.00E+00
44	440	5.21E-01	0.00E+00	0.00E+00
45	450	3.98E-01	0.00E+00	0.00E+00
46	460	3.03E-01	0.00E+00	0.00E+00
47	470	2.32E-01	0.00E+00	0.00E+00
48	480	1.77E-01	0.00E+00	0.00E+00
49	490	1.35E-01	0.00E+00	0.00E+00
50	500	1.03E-01	0.00E+00	0.00E+00
51	510	7.86E-02	0.00E+00	0.00E+00
52	520	6.00E-02	0.00E+00	0.00E+00
53	530	4.58E-02	0.00E+00	0.00E+00
54	540	3.49E-02	0.00E+00	0.00E+00
55	550	2.67E-02	0.00E+00	0.00E+00
56	560	2.03E-02	0.00E+00	0.00E+00
57	570	1.55E-02	0.00E+00	0.00E+00
58	580	1.18E-02	0.00E+00	0.00E+00
59	590	9.04E-03	0.00E+00	0.00E+00
60	600	6.90E-03	0.00E+00	0.00E+00
61	610	5.27E-03	0.00E+00	0.00E+00
62	620	4.02E-03	0.00E+00	0.00E+00
63	630	3.07E-03	0.00E+00	0.00E+00
64	640	2.34E-03	0.00E+00	0.00E+00
65	650	1.79E-03	0.00E+00	0.00E+00
66	660	1.36E-03	0.00E+00	0.00E+00
67	670	1.04E-03	0.00E+00	0.00E+00
68	680	7.94E-04	1.98E-06	9.89E-06
69	690	6.06E-04	1.09E-05	7.41E-05
70	700	4.63E-04	1.32E-05	1.95E-04
71	710	3.53E-04	1.01E-05	3.11E-04
72	720	2.69E-04	7.70E-06	4.00E-04
73	730	2.06E-04	5.88E-06	4.68E-04
74	740	1.57E-04	4.49E-06	5.20E-04
75	750	1.20E-04	3.42E-06	5.59E-04
76	760	9.14E-05	2.61E-06	5.90E-04
77	770	6.98E-05	1.99E-06	6.13E-04
78	780	5.32E-05	1.52E-06	6.30E-04
79	790	4.06E-05	1.16E-06	6.44E-04
80	800	3.10E-05	8.87E-07	6.54E-04
81	810	2.37E-05	6.77E-07	6.62E-04
82	820	1.81E-05	5.16E-07	6.68E-04
83	830	1.38E-05	3.94E-07	6.72E-04
84	840	1.05E-05	3.01E-07	6.76E-04
85	850	8.03E-06	2.30E-07	6.78E-04
86	860	6.13E-06	1.75E-07	6.80E-04
87	870	4.68E-06	1.34E-07	6.82E-04
88	880	3.57E-06	1.02E-07	6.83E-04
89	890	2.72E-06	7.79E-08	6.84E-04
90	900	2.08E-06	5.94E-08	6.85E-04
91	910	1.59E-06	4.54E-08	6.85E-04
92	920	1.21E-06	3.46E-08	6.86E-04
93	930	9.24E-07	2.64E-08	6.86E-04
94	940	7.05E-07	2.02E-08	6.86E-04
95	950	5.38E-07	1.54E-08	6.86E-04
96	960	4.11E-07	1.17E-08	6.86E-04
97	970	3.14E-07	8.96E-09	6.87E-04
98	980	2.39E-07	6.84E-09	6.87E-04
99	990	1.83E-07	5.22E-09	6.87E-04
100	1000	1.39E-07	3.98E-09	6.87E-04





Plume Profile

x_{min} (ft) =	**0**
x_{max} (ft) =	**3000**
y (ft) =	**0**
t (yr) =	**1200**

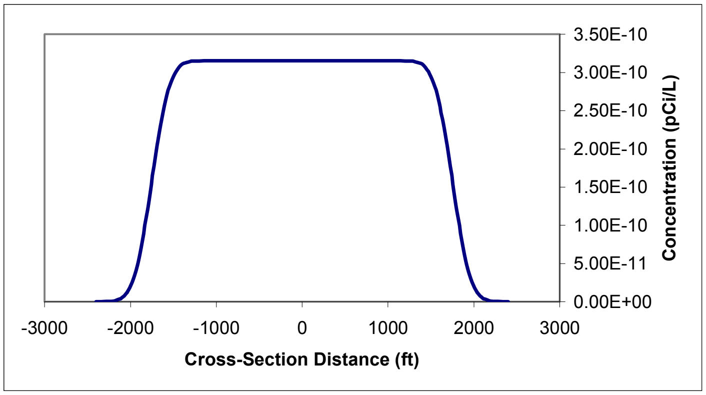


500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	2.20E-07
1	75	2.47E-07
2	150	2.72E-07
3	225	2.94E-07
4	300	3.12E-07
5	375	3.25E-07
6	450	3.30E-07
7	525	3.27E-07
8	600	3.17E-07
9	675	3.02E-07
10	750	2.85E-07
11	825	2.64E-07
12	900	2.42E-07
13	975	2.18E-07
14	1050	1.94E-07
15	1125	1.69E-07
16	1200	1.46E-07
17	1275	1.23E-07
18	1350	1.03E-07
19	1425	8.42E-08
20	1500	6.78E-08
21	1575	5.36E-08
22	1650	4.16E-08
23	1725	3.18E-08
24	1800	2.38E-08
25	1875	1.75E-08
26	1950	1.26E-08
27	2025	8.89E-09
28	2100	6.16E-09
29	2175	4.18E-09
30	2250	2.78E-09
31	2325	1.81E-09
32	2400	1.16E-09
33	2475	7.23E-10
34	2550	4.43E-10
35	2625	2.65E-10
36	2700	1.56E-10
37	2775	8.92E-11
38	2850	5.01E-11
39	2925	2.75E-11
40	3000	1.48E-11

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2400
t (yr) =	1200

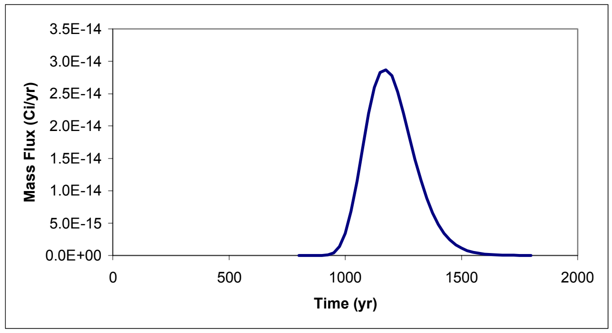


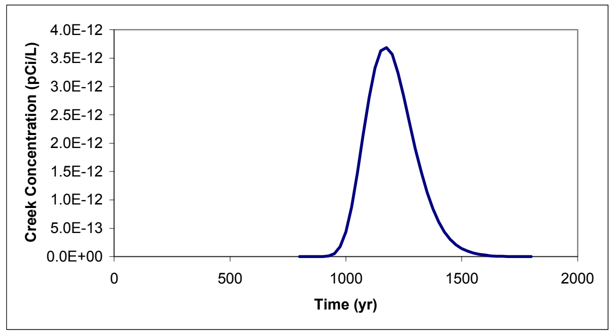
	y (ft)	C(x,y,t)
0	-2400	1.23E-14
1	-2280	1.96E-13
2	-2160	1.94E-12
3	-2040	1.20E-11
4	-1920	4.70E-11
5	-1800	1.20E-10
6	-1680	2.10E-10
7	-1560	2.77E-10
8	-1440	3.06E-10
9	-1320	3.14E-10
10	-1200	3.15E-10
11	-1080	3.15E-10
12	-960	3.15E-10
13	-840	3.15E-10
14	-720	3.15E-10
15	-600	3.15E-10
16	-480	3.15E-10
17	-360	3.15E-10
18	-240	3.15E-10
19	-120	3.15E-10
20	0	3.15E-10
21	120	3.15E-10
22	240	3.15E-10
23	360	3.15E-10
24	480	3.15E-10
25	600	3.15E-10
26	720	3.15E-10
27	840	3.15E-10
28	960	3.15E-10
29	1080	3.15E-10
30	1200	3.15E-10
31	1320	3.14E-10
32	1440	3.06E-10
33	1560	2.77E-10
34	1680	2.10E-10
35	1800	1.20E-10
36	1920	4.70E-11
37	2040	1.20E-11
38	2160	1.94E-12
39	2280	1.96E-13
40	2400	1.23E-14

Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	800
t_{max} (yr) =	1800

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	800	9.53E-26	0.00E+00	1.22E-23
1	825	1.76E-22	2.20E-21	2.25E-20
2	850	2.43E-20	3.08E-19	3.11E-18
3	875	8.57E-19	1.13E-17	1.10E-16
4	900	1.22E-17	1.74E-16	1.56E-15
5	925	9.11E-17	1.46E-15	1.17E-14
6	950	4.22E-16	7.88E-15	5.41E-14
7	975	1.38E-15	3.04E-14	1.77E-13
8	1000	3.41E-15	9.03E-14	4.38E-13
9	1025	6.83E-15	2.18E-13	8.76E-13
10	1050	1.15E-14	4.47E-13	1.47E-12
11	1075	1.68E-14	8.00E-13	2.15E-12
12	1100	2.19E-14	1.28E-12	2.81E-12
13	1125	2.59E-14	1.88E-12	3.33E-12
14	1150	2.83E-14	2.56E-12	3.63E-12
15	1175	2.87E-14	3.27E-12	3.68E-12
16	1200	2.78E-14	3.98E-12	3.56E-12
17	1225	2.53E-14	4.64E-12	3.24E-12
18	1250	2.20E-14	5.23E-12	2.82E-12
19	1275	1.84E-14	5.74E-12	2.36E-12
20	1300	1.49E-14	6.16E-12	1.90E-12
21	1325	1.16E-14	6.49E-12	1.49E-12
22	1350	8.87E-15	6.74E-12	1.14E-12
23	1375	6.60E-15	6.94E-12	8.46E-13
24	1400	4.80E-15	7.08E-12	6.16E-13
25	1425	3.43E-15	7.18E-12	4.39E-13
26	1450	2.40E-15	7.25E-12	3.08E-13
27	1475	1.65E-15	7.30E-12	2.11E-13
28	1500	1.12E-15	7.34E-12	1.43E-13
29	1525	7.44E-16	7.36E-12	9.54E-14
30	1550	4.92E-16	7.38E-12	6.30E-14
31	1575	3.21E-16	7.39E-12	4.12E-14
32	1600	2.07E-16	7.39E-12	2.66E-14
33	1625	1.33E-16	7.40E-12	1.70E-14
34	1650	8.33E-17	7.40E-12	1.07E-14
35	1675	5.23E-17	7.40E-12	6.70E-15
36	1700	3.25E-17	7.40E-12	4.17E-15
37	1725	2.01E-17	7.41E-12	2.57E-15
38	1750	1.23E-17	7.41E-12	1.58E-15
39	1775	7.48E-18	7.41E-12	9.59E-16
40	1800	4.52E-18	7.41E-12	5.80E-16



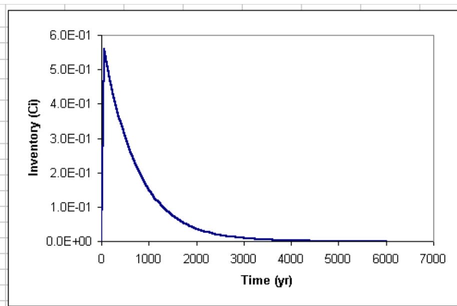


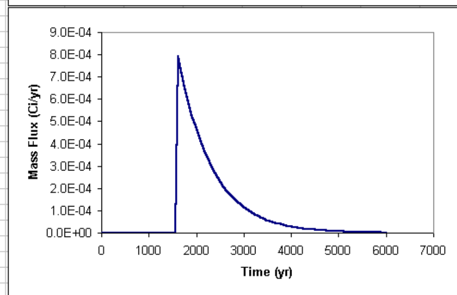
U^{235}

	A	B	C	D	E	F	G	H	I	J	K
1											
2		***Groundwater Transport - SRS ORWBG***									
3											
4		***Delivered Inventory and Nulide Decay***					***Summary***				
5		**I_o (Ci)**	**6.00E-01**	λ_D (yr^{-1})	0.0000		**Total Flux to Water Table (Ci) =**				**5.94E-01**
6		**Δt_R (yr)**	**5**	I_m (Ci/yr)	0		**Total Flux to Creek (Ci) =**				**5.99E-01**
7		**Δt_O (yr)**	**20**				**Maximum Flux to Water Table (Ci/yr) =**				**7.94E-04**
8		**$T_{1/2}$ (yr)**	**7.10E+08**				**Maximum Flux to Creek (Ci/yr) =**				**1.69E-04**
9							**Maximum Creek Concentration (pCi/L) =**				**2.16E-02**
10		***Leaching***									
11		**q_f (ft/yr)**	**1.25**	λ_L (yr^{-1})	0.0013889						
12		**f_L**	**1.00**	I_{max} (Ci)	1						
13		**θ_{waste}**	**0.25**								
14		**ρ_{waste} (kg/L)**	**1.6**								
15		**K_d^w (L/kg)**	**35**								
16		**L_{waste} (ft)**	**16**								
17											
18		***Vadose Zone***									
19		**L_{vz} (ft)**	**35**	Δt_{vz} (yr)	1573.6						
20		**θ_{vz}**	**0.2**								
21											
22		***Aquifer Parameters***									
23		**q_x (ft/yr)**	**40**	R	225						
24		**n**	**0.25**	D_{xx}' (ft^2/yr)	96						
25		**a_L (ft)**	**135**	D_{yy}' (ft^2/yr)	12						
26		**a_T (ft)**	**17**	v_x' (ft/yr)	0.711						
27		**L (ft)**	**1000**	c_o/M (ft^{-3})	5.77E-11						
28		**W (ft)**	**3500**								
29		**H (ft)**	**22**								
30		**ρ_b (kg/L)**	**1.6**								
31		**K_d (L/kg)**	**35**								
32											
33		***Creek Discharge***									
34		**Q_c (m^3/yr)**	**7.80E+06**								
35											
36		***Integral Convergence Criteria***									
37		**ε_1**	**0.001**	**Local Concentration**							
38		**ε_2**	**0.01**	**Creek Flux**							

Inventory and Water Table Flux

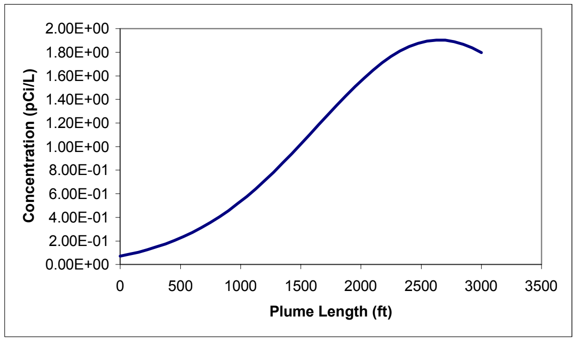
	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	6000		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	60	5.61E-01	0.00E+00	0.00E+00
2	120	5.16E-01	0.00E+00	0.00E+00
3	180	4.75E-01	0.00E+00	0.00E+00
4	240	4.37E-01	0.00E+00	0.00E+00
5	300	4.02E-01	0.00E+00	0.00E+00
6	360	3.70E-01	0.00E+00	0.00E+00
7	420	3.40E-01	0.00E+00	0.00E+00
8	480	3.13E-01	0.00E+00	0.00E+00
9	540	2.88E-01	0.00E+00	0.00E+00
10	600	2.65E-01	0.00E+00	0.00E+00
11	660	2.44E-01	0.00E+00	0.00E+00
12	720	2.24E-01	0.00E+00	0.00E+00
13	780	2.06E-01	0.00E+00	0.00E+00
14	840	1.90E-01	0.00E+00	0.00E+00
15	900	1.75E-01	0.00E+00	0.00E+00
16	960	1.61E-01	0.00E+00	0.00E+00
17	1020	1.48E-01	0.00E+00	0.00E+00
18	1080	1.36E-01	0.00E+00	0.00E+00
19	1140	1.25E-01	0.00E+00	0.00E+00
20	1200	1.15E-01	0.00E+00	0.00E+00
21	1260	1.06E-01	0.00E+00	0.00E+00
22	1320	9.74E-02	0.00E+00	0.00E+00
23	1380	8.96E-02	0.00E+00	0.00E+00
24	1440	8.25E-02	0.00E+00	0.00E+00
25	1500	7.59E-02	0.00E+00	0.00E+00
26	1560	6.98E-02	0.00E+00	0.00E+00
27	1620	6.42E-02	7.94E-04	2.38E-02
28	1680	5.91E-02	7.30E-04	6.95E-02
29	1740	5.44E-02	6.72E-04	1.12E-01
30	1800	5.00E-02	6.18E-04	1.50E-01
31	1860	4.60E-02	5.69E-04	1.86E-01
32	1920	4.23E-02	5.23E-04	2.19E-01
33	1980	3.90E-02	4.81E-04	2.49E-01
34	2040	3.58E-02	4.43E-04	2.76E-01
35	2100	3.30E-02	4.07E-04	3.02E-01
36	2160	3.03E-02	3.75E-04	3.25E-01
37	2220	2.79E-02	3.45E-04	3.47E-01
38	2280	2.57E-02	3.17E-04	3.67E-01
39	2340	2.36E-02	2.92E-04	3.85E-01
40	2400	2.17E-02	2.69E-04	4.02E-01
41	2460	2.00E-02	2.47E-04	4.17E-01
42	2520	1.84E-02	2.27E-04	4.32E-01
43	2580	1.69E-02	2.09E-04	4.45E-01
44	2640	1.56E-02	1.92E-04	4.57E-01
45	2700	1.43E-02	1.77E-04	4.68E-01
46	2760	1.32E-02	1.63E-04	4.78E-01
47	2820	1.21E-02	1.50E-04	4.88E-01
48	2880	1.12E-02	1.38E-04	4.96E-01
49	2940	1.03E-02	1.27E-04	5.04E-01
50	3000	9.45E-03	1.17E-04	5.11E-01
51	3060	8.69E-03	1.07E-04	5.18E-01
52	3120	8.00E-03	9.88E-05	5.24E-01
53	3180	7.36E-03	9.09E-05	5.30E-01
54	3240	6.77E-03	8.36E-05	5.35E-01
55	3300	6.23E-03	7.70E-05	5.40E-01
56	3360	5.73E-03	7.08E-05	5.45E-01
57	3420	5.27E-03	6.51E-05	5.49E-01
58	3480	4.85E-03	5.99E-05	5.52E-01
59	3540	4.46E-03	5.51E-05	5.56E-01
60	3600	4.11E-03	5.07E-05	5.59E-01
61	3660	3.78E-03	4.67E-05	5.62E-01
62	3720	3.48E-03	4.29E-05	5.65E-01
63	3780	3.20E-03	3.95E-05	5.67E-01
64	3840	2.94E-03	3.64E-05	5.69E-01
65	3900	2.71E-03	3.34E-05	5.71E-01
66	3960	2.49E-03	3.08E-05	5.73E-01
67	4020	2.29E-03	2.83E-05	5.75E-01
68	4080	2.11E-03	2.60E-05	5.77E-01
69	4140	1.94E-03	2.40E-05	5.78E-01
70	4200	1.78E-03	2.20E-05	5.80E-01
71	4260	1.64E-03	2.03E-05	5.81E-01
72	4320	1.51E-03	1.87E-05	5.82E-01
73	4380	1.39E-03	1.72E-05	5.83E-01
74	4440	1.28E-03	1.58E-05	5.84E-01
75	4500	1.18E-03	1.45E-05	5.85E-01
76	4560	1.08E-03	1.34E-05	5.86E-01
77	4620	9.96E-04	1.23E-05	5.87E-01
78	4680	9.16E-04	1.13E-05	5.87E-01
79	4740	8.43E-04	1.04E-05	5.88E-01
80	4800	7.76E-04	9.58E-06	5.89E-01
81	4860	7.14E-04	8.82E-06	5.89E-01
82	4920	6.56E-04	8.11E-06	5.90E-01
83	4980	6.04E-04	7.46E-06	5.90E-01
84	5040	5.56E-04	6.87E-06	5.91E-01
85	5100	5.11E-04	6.32E-06	5.91E-01
86	5160	4.70E-04	5.81E-06	5.91E-01
87	5220	4.33E-04	5.35E-06	5.92E-01
88	5280	3.98E-04	4.92E-06	5.92E-01
89	5340	3.66E-04	4.53E-06	5.92E-01
90	5400	3.37E-04	4.16E-06	5.93E-01
91	5460	3.10E-04	3.83E-06	5.93E-01
92	5520	2.85E-04	3.53E-06	5.93E-01
93	5580	2.62E-04	3.24E-06	5.93E-01
94	5640	2.42E-04	2.98E-06	5.93E-01
95	5700	2.22E-04	2.75E-06	5.94E-01
96	5760	2.04E-04	2.53E-06	5.94E-01
97	5820	1.88E-04	2.32E-06	5.94E-01
98	5880	1.73E-04	2.14E-06	5.94E-01
99	5940	1.59E-04	1.97E-06	5.94E-01
100	6000	1.46E-04	1.81E-06	5.94E-01





Plume Profile

x_{min} (ft) =	**0**
x_{max} (ft) =	**3000**
y (ft) =	**0**
t (yr) =	**6000**



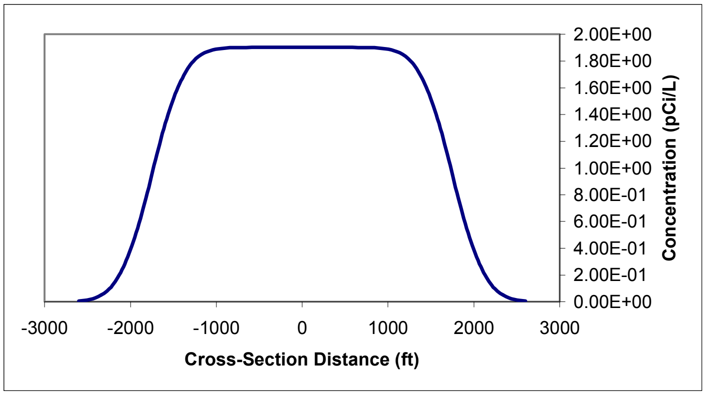
500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	7.14E-02
1	75	8.69E-02
2	150	1.05E-01
3	225	1.25E-01
4	300	1.49E-01
5	375	1.75E-01
6	450	2.04E-01
7	525	2.37E-01
8	600	2.73E-01
9	675	3.13E-01
10	750	3.57E-01
11	825	4.05E-01
12	900	4.58E-01
13	975	5.15E-01
14	1050	5.76E-01
15	1125	6.42E-01
16	1200	7.11E-01
17	1275	7.85E-01
18	1350	8.61E-01
19	1425	9.40E-01
20	1500	1.02E+00
21	1575	1.10E+00
22	1650	1.19E+00
23	1725	1.27E+00
24	1800	1.35E+00
25	1875	1.43E+00
26	1950	1.51E+00
27	2025	1.58E+00
28	2100	1.65E+00
29	2175	1.71E+00
30	2250	1.76E+00
31	2325	1.81E+00
32	2400	1.85E+00
33	2475	1.88E+00
34	2550	1.90E+00
35	2625	1.90E+00
36	2700	1.90E+00
37	2775	1.89E+00
38	2850	1.87E+00
39	2925	1.84E+00
40	3000	1.80E+00

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	6000

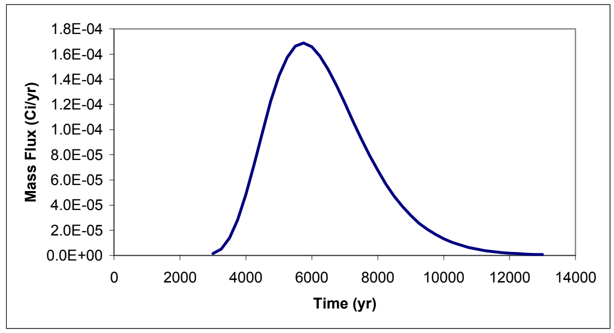
	y (ft)	C(x,y,t)
0	-2600	5.18E-03
1	-2470	1.72E-02
2	-2340	4.92E-02
3	-2210	1.22E-01
4	-2080	2.60E-01
5	-1950	4.81E-01
6	-1820	7.76E-01
7	-1690	1.10E+00
8	-1560	1.40E+00
9	-1430	1.63E+00
10	-1300	1.77E+00
11	-1170	1.85E+00
12	-1040	1.88E+00
13	-910	1.90E+00
14	-780	1.90E+00
15	-650	1.90E+00
16	-520	1.90E+00
17	-390	1.90E+00
18	-260	1.90E+00
19	-130	1.90E+00
20	0	1.90E+00
21	130	1.90E+00
22	260	1.90E+00
23	390	1.90E+00
24	520	1.90E+00
25	650	1.90E+00
26	780	1.90E+00
27	910	1.90E+00
28	1040	1.88E+00
29	1170	1.85E+00
30	1300	1.77E+00
31	1430	1.63E+00
32	1560	1.40E+00
33	1690	1.10E+00
34	1820	7.76E-01
35	1950	4.81E-01
36	2080	2.60E-01
37	2210	1.22E-01
38	2340	4.92E-02
39	2470	1.72E-02
40	2600	5.18E-03

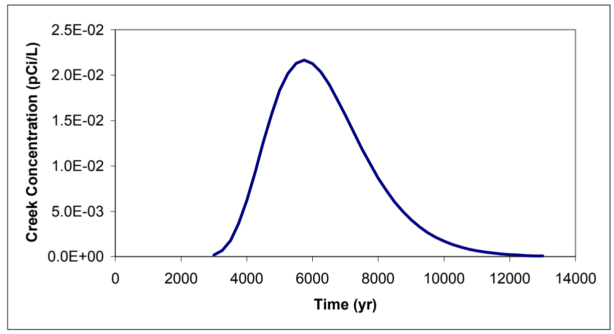


Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	3000
t_{max} (yr) =	13000

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	3000	1.37E-06	0.00E+00	1.76E-04
1	3250	5.25E-06	8.27E-04	6.73E-04
2	3500	1.38E-05	3.21E-03	1.77E-03
3	3750	2.83E-05	8.48E-03	3.63E-03
4	4000	4.85E-05	1.81E-02	6.22E-03
5	4250	7.27E-05	3.32E-02	9.32E-03
6	4500	9.82E-05	5.46E-02	1.26E-02
7	4750	1.22E-04	8.22E-02	1.57E-02
8	5000	1.43E-04	1.15E-01	1.83E-02
9	5250	1.57E-04	1.53E-01	2.02E-02
10	5500	1.66E-04	1.93E-01	2.13E-02
11	5750	1.69E-04	2.35E-01	2.16E-02
12	6000	1.66E-04	2.77E-01	2.13E-02
13	6250	1.59E-04	3.18E-01	2.03E-02
14	6500	1.48E-04	3.56E-01	1.90E-02
15	6750	1.35E-04	3.91E-01	1.73E-02
16	7000	1.21E-04	4.23E-01	1.55E-02
17	7250	1.07E-04	4.52E-01	1.37E-02
18	7500	9.29E-05	4.77E-01	1.19E-02
19	7750	7.97E-05	4.98E-01	1.02E-02
20	8000	6.75E-05	5.17E-01	8.66E-03
21	8250	5.67E-05	5.32E-01	7.26E-03
22	8500	4.71E-05	5.45E-01	6.04E-03
23	8750	3.88E-05	5.56E-01	4.97E-03
24	9000	3.17E-05	5.65E-01	4.06E-03
25	9250	2.57E-05	5.72E-01	3.30E-03
26	9500	2.07E-05	5.78E-01	2.66E-03
27	9750	1.66E-05	5.82E-01	2.13E-03
28	10000	1.32E-05	5.86E-01	1.70E-03
29	10250	1.05E-05	5.89E-01	1.35E-03
30	10500	8.27E-06	5.91E-01	1.06E-03
31	10750	6.50E-06	5.93E-01	8.33E-04
32	11000	5.08E-06	5.95E-01	6.52E-04
33	11250	3.96E-06	5.96E-01	5.08E-04
34	11500	3.07E-06	5.97E-01	3.94E-04
35	11750	2.38E-06	5.97E-01	3.05E-04
36	12000	1.84E-06	5.98E-01	2.35E-04
37	12250	1.41E-06	5.98E-01	1.81E-04
38	12500	1.08E-06	5.99E-01	1.39E-04
39	12750	8.29E-07	5.99E-01	1.06E-04
40	13000	6.33E-07	5.99E-01	8.11E-05



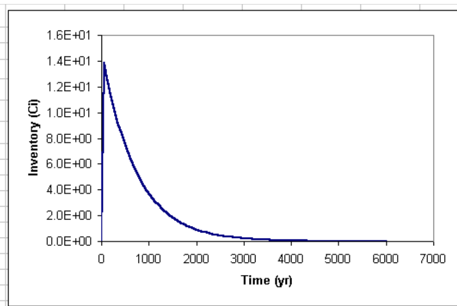


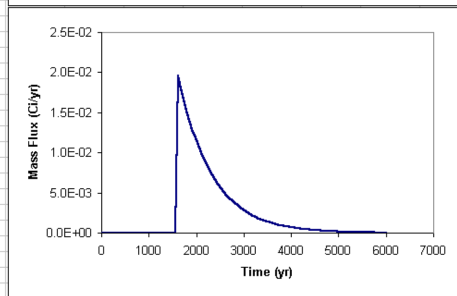
U^{238}

	A	B	C	D	E	F	G	H	I	J	K
1											
2		***Groundwater Transport - SRS ORWBG***									
3											
4		***Delivered Inventory and Nulide Decay***					***Summary***				
5		**I_o (Ci)**	**1.48E+01**	λ_D (yr^{-1})	0.0000		**Total Flux to Water Table (Ci) =**				**1.47E+01**
6		**Δt_R (yr)**	**5**	I_m (Ci/yr)	1		**Total Flux to Creek (Ci) =**				**1.48E+01**
7		**Δt_O (yr)**	**20**				**Maximum Flux to Water Table (Ci/yr) =**				**1.96E-02**
8		**$T_{1/2}$ (yr)**	**4.51E+09**				**Maximum Flux to Creek (Ci/yr) =**				**4.17E-03**
9							**Maximum Creek Concentration (pCi/L) =**				**5.35E-01**
10		***Leaching***									
11		**q_f (ft/yr)**	**1.25**	λ_L (yr^{-1})	0.0013889						
12		**f_L**	**1.00**	I_{max} (Ci)	15						
13		**θ_{waste}**	**0.25**								
14		**ρ_{waste} (kg/L)**	**1.6**								
15		**K_d^w (L/kg)**	**35**								
16		**L_{waste} (ft)**	**16**								
17											
18		***Vadose Zone***									
19		**L_{vz} (ft)**	**35**	Δt_{vz} (yr)	1573.6						
20		**θ_{vz}**	**0.2**								
21											
22		***Aquifer Parameters***									
23		**q_x (ft/yr)**	**40**	R	225						
24		**n**	**0.25**	D_{xx}' (ft^2/yr)	96						
25		**a_L (ft)**	**135**	D_{yy}' (ft^2/yr)	12						
26		**a_T (ft)**	**17**	v_x' (ft/yr)	0.711						
27		**L (ft)**	**1000**	c_o/M (ft^{-3})	5.77E-11						
28		**W (ft)**	**3500**								
29		**H (ft)**	**22**								
30		**ρ_b (kg/L)**	**1.6**								
31		**K_d (L/kg)**	**35**								
32											
33		***Creek Discharge***									
34		**Q_c (m^3/yr)**	**7.80E+06**								
35											
36		***Integral Convergence Criteria***									
37		**ε_1**	**0.01**	**Local Concentration**							
38		**ε_2**	**0.1**	**Creek Flux**							

Inventory and Water Table Flux

	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	6000		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	60	1.38E+01	0.00E+00	0.00E+00
2	120	1.27E+01	0.00E+00	0.00E+00
3	180	1.17E+01	0.00E+00	0.00E+00
4	240	1.08E+01	0.00E+00	0.00E+00
5	300	9.91E+00	0.00E+00	0.00E+00
6	360	9.12E+00	0.00E+00	0.00E+00
7	420	8.39E+00	0.00E+00	0.00E+00
8	480	7.72E+00	0.00E+00	0.00E+00
9	540	7.10E+00	0.00E+00	0.00E+00
10	600	6.53E+00	0.00E+00	0.00E+00
11	660	6.01E+00	0.00E+00	0.00E+00
12	720	5.53E+00	0.00E+00	0.00E+00
13	780	5.09E+00	0.00E+00	0.00E+00
14	840	4.68E+00	0.00E+00	0.00E+00
15	900	4.31E+00	0.00E+00	0.00E+00
16	960	3.96E+00	0.00E+00	0.00E+00
17	1020	3.65E+00	0.00E+00	0.00E+00
18	1080	3.35E+00	0.00E+00	0.00E+00
19	1140	3.09E+00	0.00E+00	0.00E+00
20	1200	2.84E+00	0.00E+00	0.00E+00
21	1260	2.61E+00	0.00E+00	0.00E+00
22	1320	2.40E+00	0.00E+00	0.00E+00
23	1380	2.21E+00	0.00E+00	0.00E+00
24	1440	2.03E+00	0.00E+00	0.00E+00
25	1500	1.87E+00	0.00E+00	0.00E+00
26	1560	1.72E+00	0.00E+00	0.00E+00
27	1620	1.58E+00	1.96E-02	5.87E-01
28	1680	1.46E+00	1.80E-02	1.71E+00
29	1740	1.34E+00	1.66E-02	2.75E+00
30	1800	1.23E+00	1.52E-02	3.71E+00
31	1860	1.14E+00	1.40E-02	4.58E+00
32	1920	1.04E+00	1.29E-02	5.39E+00
33	1980	9.61E-01	1.19E-02	6.14E+00
34	2040	8.84E-01	1.09E-02	6.82E+00
35	2100	8.13E-01	1.01E-02	7.45E+00
36	2160	7.48E-01	9.25E-03	8.03E+00
37	2220	6.89E-01	8.51E-03	8.56E+00
38	2280	6.34E-01	7.83E-03	9.05E+00
39	2340	5.83E-01	7.20E-03	9.50E+00
40	2400	5.36E-01	6.63E-03	9.92E+00
41	2460	4.93E-01	6.10E-03	1.03E+01
42	2520	4.54E-01	5.61E-03	1.06E+01
43	2580	4.18E-01	5.16E-03	1.10E+01
44	2640	3.84E-01	4.75E-03	1.13E+01
45	2700	3.54E-01	4.37E-03	1.15E+01
46	2760	3.25E-01	4.02E-03	1.18E+01
47	2820	2.99E-01	3.70E-03	1.20E+01
48	2880	2.75E-01	3.40E-03	1.22E+01
49	2940	2.53E-01	3.13E-03	1.24E+01
50	3000	2.33E-01	2.88E-03	1.26E+01
51	3060	2.14E-01	2.65E-03	1.28E+01
52	3120	1.97E-01	2.44E-03	1.29E+01
53	3180	1.82E-01	2.24E-03	1.31E+01
54	3240	1.67E-01	2.06E-03	1.32E+01
55	3300	1.54E-01	1.90E-03	1.33E+01
56	3360	1.41E-01	1.75E-03	1.34E+01
57	3420	1.30E-01	1.61E-03	1.35E+01
58	3480	1.20E-01	1.48E-03	1.36E+01
59	3540	1.10E-01	1.36E-03	1.37E+01
60	3600	1.01E-01	1.25E-03	1.38E+01
61	3660	9.32E-02	1.15E-03	1.39E+01
62	3720	8.57E-02	1.06E-03	1.39E+01
63	3780	7.89E-02	9.75E-04	1.40E+01
64	3840	7.26E-02	8.97E-04	1.40E+01
65	3900	6.68E-02	8.25E-04	1.41E+01
66	3960	6.14E-02	7.59E-04	1.41E+01
67	4020	5.65E-02	6.98E-04	1.42E+01
68	4080	5.20E-02	6.42E-04	1.42E+01
69	4140	4.78E-02	5.91E-04	1.43E+01
70	4200	4.40E-02	5.44E-04	1.43E+01
71	4260	4.05E-02	5.00E-04	1.43E+01
72	4320	3.73E-02	4.60E-04	1.44E+01
73	4380	3.43E-02	4.24E-04	1.44E+01
74	4440	3.15E-02	3.90E-04	1.44E+01
75	4500	2.90E-02	3.59E-04	1.44E+01
76	4560	2.67E-02	3.30E-04	1.45E+01
77	4620	2.46E-02	3.03E-04	1.45E+01
78	4680	2.26E-02	2.79E-04	1.45E+01
79	4740	2.08E-02	2.57E-04	1.45E+01
80	4800	1.91E-02	2.36E-04	1.45E+01
81	4860	1.76E-02	2.17E-04	1.45E+01
82	4920	1.62E-02	2.00E-04	1.45E+01
83	4980	1.49E-02	1.84E-04	1.46E+01
84	5040	1.37E-02	1.69E-04	1.46E+01
85	5100	1.26E-02	1.56E-04	1.46E+01
86	5160	1.16E-02	1.43E-04	1.46E+01
87	5220	1.07E-02	1.32E-04	1.46E+01
88	5280	9.82E-03	1.21E-04	1.46E+01
89	5340	9.04E-03	1.12E-04	1.46E+01
90	5400	8.31E-03	1.03E-04	1.46E+01
91	5460	7.65E-03	9.45E-05	1.46E+01
92	5520	7.04E-03	8.70E-05	1.46E+01
93	5580	6.48E-03	8.00E-05	1.46E+01
94	5640	5.96E-03	7.36E-05	1.46E+01
95	5700	5.48E-03	6.77E-05	1.46E+01
96	5760	5.04E-03	6.23E-05	1.46E+01
97	5820	4.64E-03	5.73E-05	1.46E+01
98	5880	4.27E-03	5.27E-05	1.47E+01
99	5940	3.93E-03	4.85E-05	1.47E+01
100	6000	3.61E-03	4.46E-05	1.47E+01

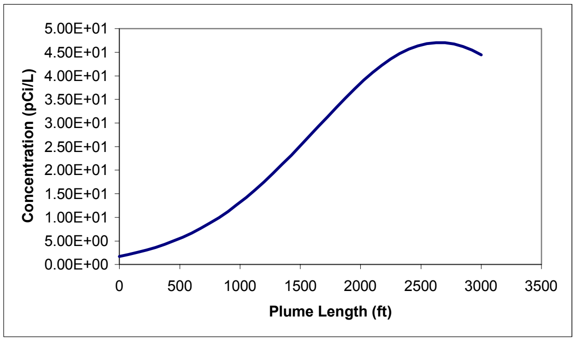




Plume Profile

x_{min} (ft) =	**0**
x_{max} (ft) =	**3000**
y (ft) =	**0**
t (yr) =	**6000**

	x (ft)	C(x;y,t)
0	0	1.75E+00
1	75	2.13E+00
2	150	2.57E+00
3	225	3.08E+00
4	300	3.65E+00
5	375	4.30E+00
6	450	5.02E+00
7	525	5.82E+00
8	600	6.70E+00
9	675	7.68E+00
10	750	8.76E+00
11	825	9.95E+00
12	900	1.12E+01
13	975	1.27E+01
14	1050	1.42E+01
15	1125	1.58E+01
16	1200	1.75E+01
17	1275	1.93E+01
18	1350	2.12E+01
19	1425	2.32E+01
20	1500	2.52E+01
21	1575	2.72E+01
22	1650	2.93E+01
23	1725	3.13E+01
24	1800	3.33E+01
25	1875	3.53E+01
26	1950	3.73E+01
27	2025	3.91E+01
28	2100	4.07E+01
29	2175	4.23E+01
30	2250	4.36E+01
31	2325	4.47E+01
32	2400	4.57E+01
33	2475	4.64E+01
34	2550	4.69E+01
35	2625	4.71E+01
36	2700	4.70E+01
37	2775	4.68E+01
38	2850	4.62E+01
39	2925	4.55E+01
40	3000	4.45E+01

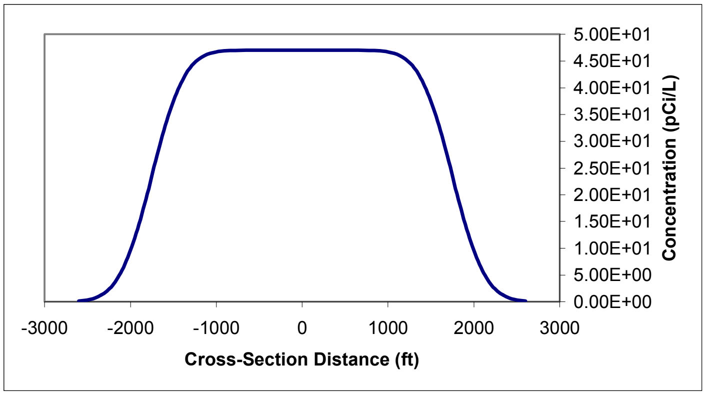


500	0
500	1.00E+08

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	6000

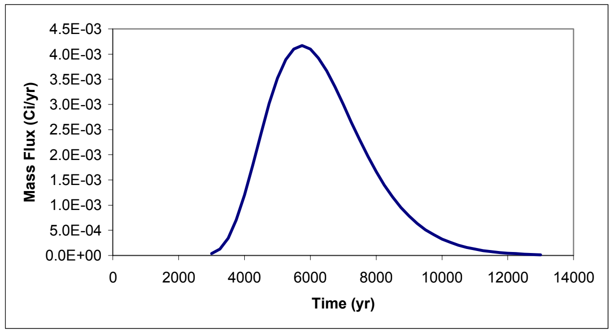
	y (ft)	C(x,y,t)
0	-2600	1.28E-01
1	-2470	4.26E-01
2	-2340	1.22E+00
3	-2210	3.01E+00
4	-2080	6.43E+00
5	-1950	1.19E+01
6	-1820	1.92E+01
7	-1690	2.72E+01
8	-1560	3.46E+01
9	-1430	4.03E+01
10	-1300	4.38E+01
11	-1170	4.57E+01
12	-1040	4.66E+01
13	-910	4.69E+01
14	-780	4.70E+01
15	-650	4.70E+01
16	-520	4.70E+01
17	-390	4.70E+01
18	-260	4.70E+01
19	-130	4.70E+01
20	0	4.70E+01
21	130	4.70E+01
22	260	4.70E+01
23	390	4.70E+01
24	520	4.70E+01
25	650	4.70E+01
26	780	4.70E+01
27	910	4.69E+01
28	1040	4.66E+01
29	1170	4.57E+01
30	1300	4.38E+01
31	1430	4.03E+01
32	1560	3.46E+01
33	1690	2.72E+01
34	1820	1.92E+01
35	1950	1.19E+01
36	2080	6.43E+00
37	2210	3.01E+00
38	2340	1.22E+00
39	2470	4.26E-01
40	2600	1.28E-01

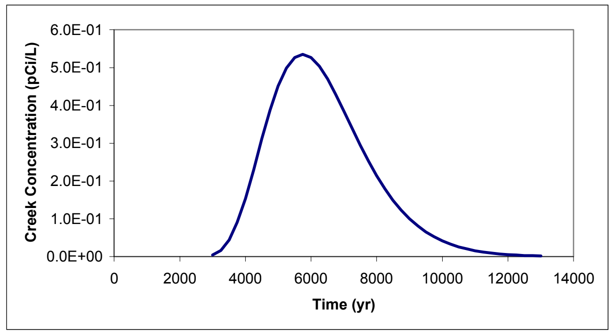


Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	3000
t_{max} (yr) =	13000

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	3000	3.41E-05	0.00E+00	4.37E-03
1	3250	1.31E-04	2.06E-02	1.67E-02
2	3500	3.44E-04	7.99E-02	4.41E-02
3	3750	7.06E-04	2.11E-01	9.06E-02
4	4000	1.20E-03	4.49E-01	1.54E-01
5	4250	1.80E-03	8.24E-01	2.30E-01
6	4500	2.43E-03	1.35E+00	3.11E-01
7	4750	3.02E-03	2.03E+00	3.87E-01
8	5000	3.52E-03	2.85E+00	4.51E-01
9	5250	3.89E-03	3.78E+00	4.99E-01
10	5500	4.11E-03	4.78E+00	5.26E-01
11	5750	4.17E-03	5.81E+00	5.35E-01
12	6000	4.10E-03	6.85E+00	5.26E-01
13	6250	3.93E-03	7.85E+00	5.03E-01
14	6500	3.67E-03	8.80E+00	4.70E-01
15	6750	3.35E-03	9.68E+00	4.29E-01
16	7000	3.00E-03	1.05E+01	3.85E-01
17	7250	2.64E-03	1.12E+01	3.39E-01
18	7500	2.30E-03	1.18E+01	2.95E-01
19	7750	1.97E-03	1.23E+01	2.53E-01
20	8000	1.67E-03	1.28E+01	2.14E-01
21	8250	1.40E-03	1.32E+01	1.79E-01
22	8500	1.16E-03	1.35E+01	1.49E-01
23	8750	9.58E-04	1.38E+01	1.23E-01
24	9000	7.82E-04	1.40E+01	1.00E-01
25	9250	6.35E-04	1.41E+01	8.14E-02
26	9500	5.11E-04	1.43E+01	6.56E-02
27	9750	4.10E-04	1.44E+01	5.25E-02
28	10000	3.26E-04	1.45E+01	4.18E-02
29	10250	2.59E-04	1.46E+01	3.32E-02
30	10500	2.04E-04	1.46E+01	2.61E-02
31	10750	1.60E-04	1.47E+01	2.05E-02
32	11000	1.25E-04	1.47E+01	1.60E-02
33	11250	9.64E-05	1.47E+01	1.24E-02
34	11500	7.49E-05	1.48E+01	9.60E-03
35	11750	5.79E-05	1.48E+01	7.43E-03
36	12000	4.47E-05	1.48E+01	5.73E-03
37	12250	3.44E-05	1.48E+01	4.41E-03
38	12500	2.64E-05	1.48E+01	3.38E-03
39	12750	2.02E-05	1.48E+01	2.59E-03
40	13000	1.54E-05	1.48E+01	1.98E-03



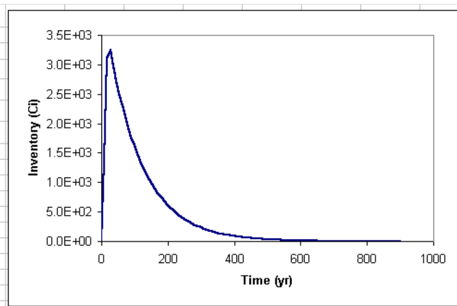


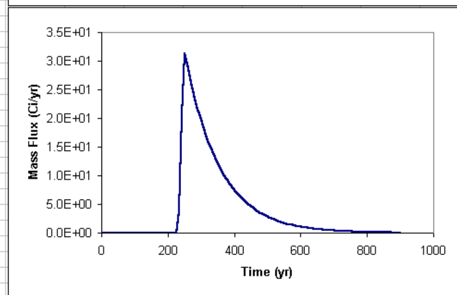
C^{14}

	A	B	C	D	E	F	G	H	I	J	K
1											
2		***Groundwater Transport - SRS ORWBG***									
3											
4		***Delivered Inventory and Nulide Decay***					***Summary***				
5		**I_o (Ci)**	**3.78E+03**	λ_D (yr^{-1})	0.0001		**Total Flux to Water Table (Ci) =**				**3.62E+03**
6		**Δt_R (yr)**	**5**	I_m (Ci/yr)	216		**Total Flux to Creek (Ci) =**				**3.38E+03**
7		**Δt_O (yr)**	**20**				**Maximum Flux to Water Table (Ci/yr) =**				**3.13E+01**
8		**$T_{1/2}$ (yr)**	**5.71E+03**				**Maximum Flux to Creek (Ci/yr) =**				**6.54E+00**
9							**Maximum Creek Concentration (pCi/L) =**				**8.39E+02**
10		***Leaching***									
11		**q_f (ft/yr)**	**1.25**	λ_L (yr^{-1})	0.0094697						
12		**f_L**	**1.00**	I_{max} (Ci)	3476						
13		**θ_{waste}**	**0.25**								
14		**ρ_{waste} (kg/L)**	**1.6**								
15		**K_d^w (L/kg)**	**5**								
16		**L_{waste} (ft)**	**16**								
17											
18		***Vadose Zone***									
19		**L_{vz} (ft)**	**35**	Δt_{vz} (yr)	229.6						
20		**θ_{vz}**	**0.2**								
21											
22		***Aquifer Parameters***									
23		**q_x (ft/yr)**	**40**	R	33						
24		**n**	**0.25**	D_{xx}' (ft^2/yr)	654.54545						
25		**a_L (ft)**	**135**	D_{yy}' (ft^2/yr)	82						
26		**a_T (ft)**	**17**	v_x' (ft/yr)	4.848						
27		**L (ft)**	**1000**	c_o/M (ft^{-3})	3.94E-10						
28		**W (ft)**	**3500**								
29		**H (ft)**	**22**								
30		**ρ_b (kg/L)**	**1.6**								
31		**K_d (L/kg)**	**5**								
32											
33		***Creek Discharge***									
34		**Q_c (m^3/yr)**	**7.80E+06**								
35											
36		***Integral Convergence Criteria***									
37		**ε_1**	**0.01**	**Local Concentration**							
38		**ε_2**	**0.1**	**Creek Flux**							

Inventory and Water Table Flux

	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	900		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	9	1.36E+03	0.00E+00	0.00E+00
2	18	3.11E+03	0.00E+00	0.00E+00
3	27	3.25E+03	0.00E+00	0.00E+00
4	36	2.98E+03	0.00E+00	0.00E+00
5	45	2.74E+03	0.00E+00	0.00E+00
6	54	2.51E+03	0.00E+00	0.00E+00
7	63	2.30E+03	0.00E+00	0.00E+00
8	72	2.11E+03	0.00E+00	0.00E+00
9	81	1.94E+03	0.00E+00	0.00E+00
10	90	1.78E+03	0.00E+00	0.00E+00
11	99	1.63E+03	0.00E+00	0.00E+00
12	108	1.49E+03	0.00E+00	0.00E+00
13	117	1.37E+03	0.00E+00	0.00E+00
14	126	1.26E+03	0.00E+00	0.00E+00
15	135	1.15E+03	0.00E+00	0.00E+00
16	144	1.06E+03	0.00E+00	0.00E+00
17	153	9.71E+02	0.00E+00	0.00E+00
18	162	8.90E+02	0.00E+00	0.00E+00
19	171	8.17E+02	0.00E+00	0.00E+00
20	180	7.49E+02	0.00E+00	0.00E+00
21	189	6.87E+02	0.00E+00	0.00E+00
22	198	6.30E+02	0.00E+00	0.00E+00
23	207	5.78E+02	0.00E+00	0.00E+00
24	216	5.31E+02	0.00E+00	0.00E+00
25	225	4.87E+02	0.00E+00	0.00E+00
26	234	4.46E+02	3.80E+00	1.71E+01
27	243	4.09E+02	2.06E+01	1.27E+02
28	252	3.76E+02	3.13E+01	3.60E+02
29	261	3.45E+02	2.87E+01	6.30E+02
30	270	3.16E+02	2.63E+01	8.77E+02
31	279	2.90E+02	2.41E+01	1.10E+03
32	288	2.66E+02	2.22E+01	1.31E+03
33	297	2.44E+02	2.03E+01	1.50E+03
34	306	2.24E+02	1.86E+01	1.68E+03
35	315	2.05E+02	1.71E+01	1.84E+03
36	324	1.88E+02	1.57E+01	1.99E+03
37	333	1.73E+02	1.44E+01	2.12E+03
38	342	1.58E+02	1.32E+01	2.25E+03
39	351	1.45E+02	1.21E+01	2.36E+03
40	360	1.33E+02	1.11E+01	2.47E+03
41	369	1.22E+02	1.02E+01	2.56E+03
42	378	1.12E+02	9.34E+00	2.65E+03
43	387	1.03E+02	8.57E+00	2.73E+03
44	396	9.44E+01	7.86E+00	2.80E+03
45	405	8.66E+01	7.21E+00	2.87E+03
46	414	7.94E+01	6.62E+00	2.93E+03
47	423	7.29E+01	6.07E+00	2.99E+03
48	432	6.68E+01	5.57E+00	3.04E+03
49	441	6.13E+01	5.11E+00	3.09E+03
50	450	5.62E+01	4.68E+00	3.14E+03
51	459	5.16E+01	4.30E+00	3.18E+03
52	468	4.73E+01	3.94E+00	3.21E+03
53	477	4.34E+01	3.62E+00	3.25E+03
54	486	3.98E+01	3.32E+00	3.28E+03
55	495	3.65E+01	3.04E+00	3.31E+03
56	504	3.35E+01	2.79E+00	3.33E+03
57	513	3.07E+01	2.56E+00	3.36E+03
58	522	2.82E+01	2.35E+00	3.38E+03
59	531	2.59E+01	2.15E+00	3.40E+03
60	540	2.37E+01	1.98E+00	3.42E+03
61	549	2.18E+01	1.81E+00	3.43E+03
62	558	2.00E+01	1.66E+00	3.45E+03
63	567	1.83E+01	1.52E+00	3.46E+03
64	576	1.68E+01	1.40E+00	3.48E+03
65	585	1.54E+01	1.28E+00	3.49E+03
66	594	1.41E+01	1.18E+00	3.50E+03
67	603	1.30E+01	1.08E+00	3.51E+03
68	612	1.19E+01	9.90E-01	3.52E+03
69	621	1.09E+01	9.09E-01	3.53E+03
70	630	1.00E+01	8.33E-01	3.54E+03
71	639	9.18E+00	7.64E-01	3.54E+03
72	648	8.42E+00	7.01E-01	3.55E+03
73	657	7.72E+00	6.43E-01	3.56E+03
74	666	7.08E+00	5.90E-01	3.56E+03
75	675	6.50E+00	5.41E-01	3.57E+03
76	684	5.96E+00	4.96E-01	3.57E+03
77	693	5.47E+00	4.55E-01	3.58E+03
78	702	5.02E+00	4.18E-01	3.58E+03
79	711	4.60E+00	3.83E-01	3.58E+03
80	720	4.22E+00	3.52E-01	3.59E+03
81	729	3.87E+00	3.22E-01	3.59E+03
82	738	3.55E+00	2.96E-01	3.59E+03
83	747	3.26E+00	2.71E-01	3.60E+03
84	756	2.99E+00	2.49E-01	3.60E+03
85	765	2.74E+00	2.28E-01	3.60E+03
86	774	2.51E+00	2.09E-01	3.60E+03
87	783	2.31E+00	1.92E-01	3.60E+03
88	792	2.12E+00	1.76E-01	3.61E+03
89	801	1.94E+00	1.62E-01	3.61E+03
90	810	1.78E+00	1.48E-01	3.61E+03
91	819	1.63E+00	1.36E-01	3.61E+03
92	828	1.50E+00	1.25E-01	3.61E+03
93	837	1.37E+00	1.14E-01	3.61E+03
94	846	1.26E+00	1.05E-01	3.61E+03
95	855	1.16E+00	9.63E-02	3.61E+03
96	864	1.06E+00	8.83E-02	3.61E+03
97	873	9.73E-01	8.10E-02	3.62E+03
98	882	8.92E-01	7.43E-02	3.62E+03
99	891	8.19E-01	6.82E-02	3.62E+03
100	900	7.51E-01	6.25E-02	3.62E+03

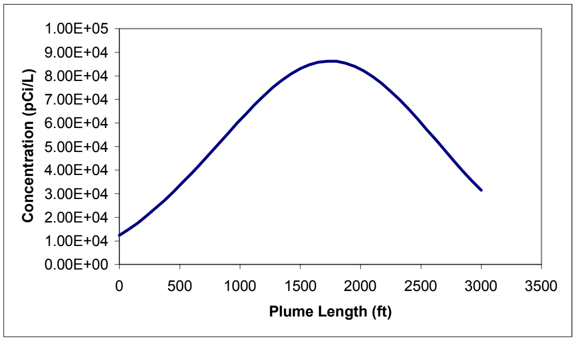




Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	700

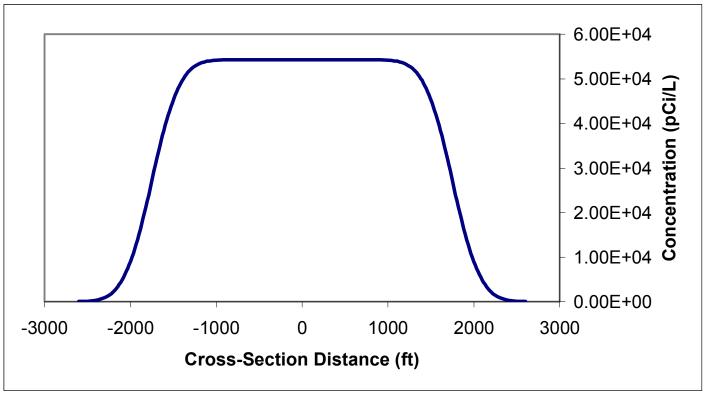
	x (ft)	C(x;y,t)
0	0	1.24E+04
1	75	1.49E+04
2	150	1.76E+04
3	225	2.06E+04
4	300	2.39E+04
5	375	2.73E+04
6	450	3.10E+04
7	525	3.48E+04
8	600	3.88E+04
9	675	4.28E+04
10	750	4.70E+04
11	825	5.13E+04
12	900	5.56E+04
13	975	5.98E+04
14	1050	6.40E+04
15	1125	6.80E+04
16	1200	7.17E+04
17	1275	7.52E+04
18	1350	7.82E+04
19	1425	8.09E+04
20	1500	8.31E+04
21	1575	8.47E+04
22	1650	8.58E+04
23	1725	8.63E+04
24	1800	8.61E+04
25	1875	8.54E+04
26	1950	8.41E+04
27	2025	8.22E+04
28	2100	7.98E+04
29	2175	7.69E+04
30	2250	7.35E+04
31	2325	6.98E+04
32	2400	6.58E+04
33	2475	6.16E+04
34	2550	5.73E+04
35	2625	5.28E+04
36	2700	4.83E+04
37	2775	4.39E+04
38	2850	3.96E+04
39	2925	3.54E+04
40	3000	3.15E+04



500	0
500	1.00E+08

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	700

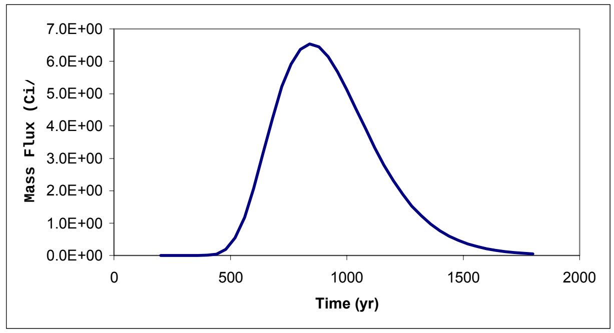


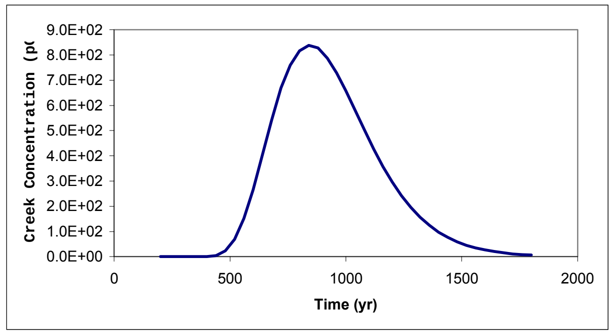
	y (ft)	C(x,y,t)
0	-2600	3.03E+01
1	-2470	1.53E+02
2	-2340	6.20E+02
3	-2210	2.03E+03
4	-2080	5.43E+03
5	-1950	1.18E+04
6	-1820	2.13E+04
7	-1690	3.22E+04
8	-1560	4.18E+04
9	-1430	4.85E+04
10	-1300	5.21E+04
11	-1170	5.36E+04
12	-1040	5.41E+04
13	-910	5.43E+04
14	-780	5.43E+04
15	-650	5.43E+04
16	-520	5.43E+04
17	-390	5.43E+04
18	-260	5.43E+04
19	-130	5.43E+04
20	0	5.43E+04
21	130	5.43E+04
22	260	5.43E+04
23	390	5.43E+04
24	520	5.43E+04
25	650	5.43E+04
26	780	5.43E+04
27	910	5.43E+04
28	1040	5.41E+04
29	1170	5.36E+04
30	1300	5.21E+04
31	1430	4.85E+04
32	1560	4.18E+04
33	1690	3.22E+04
34	1820	2.13E+04
35	1950	1.18E+04
36	2080	5.43E+03
37	2210	2.03E+03
38	2340	6.20E+02
39	2470	1.53E+02
40	2600	3.03E+01

Creek Flux and Concentration

X_c (ft) =	**2600**
y_{max} (ft) =	**2600**
t_{min} (yr) =	**200**
t_{max} (yr) =	**1800**

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	200	0.00E+00	0.00E+00	0.00E+00
1	240	0.00E+00	0.00E+00	0.00E+00
2	280	1.15E-15	2.30E-14	1.47E-13
3	320	6.32E-08	1.26E-06	8.11E-06
4	360	8.33E-05	1.67E-03	1.07E-02
5	400	3.80E-03	7.93E-02	4.87E-01
6	440	4.03E-02	9.61E-01	5.16E+00
7	480	1.85E-01	5.47E+00	2.37E+01
8	520	5.41E-01	2.00E+01	6.94E+01
9	560	1.18E+00	5.43E+01	1.51E+02
10	600	2.07E+00	1.19E+02	2.65E+02
11	640	3.15E+00	2.24E+02	4.03E+02
12	680	4.23E+00	3.71E+02	5.42E+02
13	720	5.22E+00	5.60E+02	6.70E+02
14	760	5.92E+00	7.83E+02	7.59E+02
15	800	6.37E+00	1.03E+03	8.17E+02
16	840	6.54E+00	1.29E+03	8.39E+02
17	880	6.45E+00	1.55E+03	8.27E+02
18	920	6.14E+00	1.80E+03	7.87E+02
19	960	5.68E+00	2.04E+03	7.28E+02
20	1000	5.13E+00	2.25E+03	6.57E+02
21	1040	4.53E+00	2.44E+03	5.80E+02
22	1080	3.92E+00	2.61E+03	5.03E+02
23	1120	3.33E+00	2.76E+03	4.27E+02
24	1160	2.79E+00	2.88E+03	3.58E+02
25	1200	2.31E+00	2.98E+03	2.96E+02
26	1240	1.89E+00	3.07E+03	2.42E+02
27	1280	1.53E+00	3.13E+03	1.96E+02
28	1320	1.22E+00	3.19E+03	1.57E+02
29	1360	9.69E-01	3.23E+03	1.24E+02
30	1400	7.60E-01	3.27E+03	9.74E+01
31	1440	5.93E-01	3.30E+03	7.61E+01
32	1480	4.61E-01	3.32E+03	5.91E+01
33	1520	3.56E-01	3.33E+03	4.56E+01
34	1560	2.73E-01	3.35E+03	3.50E+01
35	1600	2.08E-01	3.35E+03	2.67E+01
36	1640	1.58E-01	3.36E+03	2.03E+01
37	1680	1.19E-01	3.37E+03	1.52E+01
38	1720	8.94E-02	3.37E+03	1.15E+01
39	1760	6.71E-02	3.38E+03	8.60E+00
40	1800	5.02E-02	3.38E+03	6.44E+00





Co^{60}

Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	1.96E+06	λ_D (yr^{-1})	0.1315
Δt_R (yr)	5	I_m (Ci/yr)	100533
Δt_O (yr)	22		
$T_{1/2}$ (yr)	5.27E+00		

Summary

Total Flux to Water Table (Ci) =	**8.42E-22**
Total Flux to Creek (Ci) =	**7.84E-39**
Maximum Flux to Water Table (Ci/yr) =	**3.91E-23**
Maximum Flux to Creek (Ci/yr) =	**1.18E-40**
Maximum Creek Concentration (pCi/L) =	**1.51E-38**

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.0048077
f_L	1.00	I_{max} (Ci)	684739
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^w (L/kg)	10		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	453.6
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	65
n	0.25	D_{xx}' (ft^2/yr)	332.30769
a_L (ft)	135	D_{yy}' (ft^2/yr)	42
a_T (ft)	17	v_x' (ft/yr)	2.462
L (ft)	1000	c_o/M (ft^{-3})	2.00E-10
W (ft)	3500		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	10		

Creek Discharge

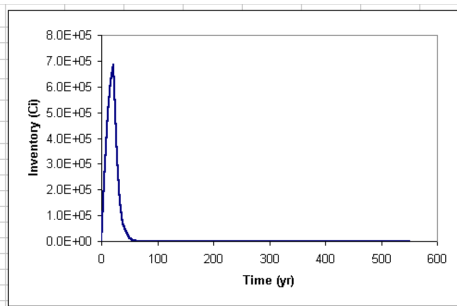
Q_c (m^3/yr)	7.80E+06

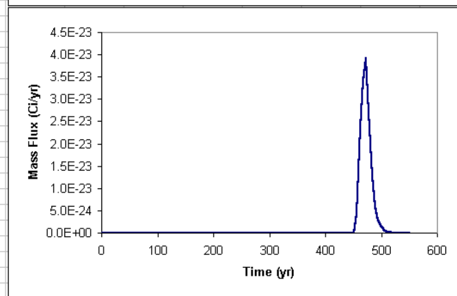
Integral Convergence Criteria

ε_1	0.01	**Local Concentration**
ε_2	0.1	**Creek Flux**

Inventory and Water Table Flux

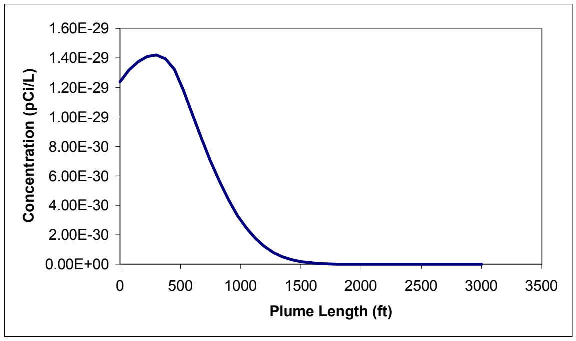
	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	550		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	5.5	2.38E+05	0.00E+00	0.00E+00
2	11	5.01E+05	0.00E+00	0.00E+00
3	16.5	6.26E+05	0.00E+00	0.00E+00
4	22	6.85E+05	0.00E+00	0.00E+00
5	27.5	3.23E+05	0.00E+00	0.00E+00
6	33	1.53E+05	0.00E+00	0.00E+00
7	38.5	7.22E+04	0.00E+00	0.00E+00
8	44	3.41E+04	0.00E+00	0.00E+00
9	49.5	1.61E+04	0.00E+00	0.00E+00
10	55	7.61E+03	0.00E+00	0.00E+00
11	60.5	3.60E+03	0.00E+00	0.00E+00
12	66	1.70E+03	0.00E+00	0.00E+00
13	71.5	8.03E+02	0.00E+00	0.00E+00
14	77	3.79E+02	0.00E+00	0.00E+00
15	82.5	1.79E+02	0.00E+00	0.00E+00
16	88	8.47E+01	0.00E+00	0.00E+00
17	93.5	4.00E+01	0.00E+00	0.00E+00
18	99	1.89E+01	0.00E+00	0.00E+00
19	104.5	8.93E+00	0.00E+00	0.00E+00
20	110	4.22E+00	0.00E+00	0.00E+00
21	115.5	1.99E+00	0.00E+00	0.00E+00
22	121	9.41E-01	0.00E+00	0.00E+00
23	126.5	4.45E-01	0.00E+00	0.00E+00
24	132	2.10E-01	0.00E+00	0.00E+00
25	137.5	9.93E-02	0.00E+00	0.00E+00
26	143	4.69E-02	0.00E+00	0.00E+00
27	148.5	2.22E-02	0.00E+00	0.00E+00
28	154	1.05E-02	0.00E+00	0.00E+00
29	159.5	4.95E-03	0.00E+00	0.00E+00
30	165	2.34E-03	0.00E+00	0.00E+00
31	170.5	1.10E-03	0.00E+00	0.00E+00
32	176	5.22E-04	0.00E+00	0.00E+00
33	181.5	2.46E-04	0.00E+00	0.00E+00
34	187	1.16E-04	0.00E+00	0.00E+00
35	192.5	5.50E-05	0.00E+00	0.00E+00
36	198	2.60E-05	0.00E+00	0.00E+00
37	203.5	1.23E-05	0.00E+00	0.00E+00
38	209	5.80E-06	0.00E+00	0.00E+00
39	214.5	2.74E-06	0.00E+00	0.00E+00
40	220	1.29E-06	0.00E+00	0.00E+00
41	225.5	6.12E-07	0.00E+00	0.00E+00
42	231	2.89E-07	0.00E+00	0.00E+00
43	236.5	1.36E-07	0.00E+00	0.00E+00
44	242	6.45E-08	0.00E+00	0.00E+00
45	247.5	3.05E-08	0.00E+00	0.00E+00
46	253	1.44E-08	0.00E+00	0.00E+00
47	258.5	6.80E-09	0.00E+00	0.00E+00
48	264	3.21E-09	0.00E+00	0.00E+00
49	269.5	1.52E-09	0.00E+00	0.00E+00
50	275	7.17E-10	0.00E+00	0.00E+00
51	280.5	3.39E-10	0.00E+00	0.00E+00
52	286	1.60E-10	0.00E+00	0.00E+00
53	291.5	7.56E-11	0.00E+00	0.00E+00
54	297	3.57E-11	0.00E+00	0.00E+00
55	302.5	1.69E-11	0.00E+00	0.00E+00
56	308	7.97E-12	0.00E+00	0.00E+00
57	313.5	3.77E-12	0.00E+00	0.00E+00
58	319	1.78E-12	0.00E+00	0.00E+00
59	324.5	8.41E-13	0.00E+00	0.00E+00
60	330	3.97E-13	0.00E+00	0.00E+00
61	335.5	1.88E-13	0.00E+00	0.00E+00
62	341	8.87E-14	0.00E+00	0.00E+00
63	346.5	4.19E-14	0.00E+00	0.00E+00
64	352	1.98E-14	0.00E+00	0.00E+00
65	357.5	9.35E-15	0.00E+00	0.00E+00
66	363	4.42E-15	0.00E+00	0.00E+00
67	368.5	2.09E-15	0.00E+00	0.00E+00
68	374	9.86E-16	0.00E+00	0.00E+00
69	379.5	4.66E-16	0.00E+00	0.00E+00
70	385	2.20E-16	0.00E+00	0.00E+00
71	390.5	1.04E-16	0.00E+00	0.00E+00
72	396	4.91E-17	0.00E+00	0.00E+00
73	401.5	2.32E-17	0.00E+00	0.00E+00
74	407	1.10E-17	0.00E+00	0.00E+00
75	412.5	5.18E-18	0.00E+00	0.00E+00
76	418	2.45E-18	0.00E+00	0.00E+00
77	423.5	1.16E-18	0.00E+00	0.00E+00
78	429	5.46E-19	0.00E+00	0.00E+00
79	434.5	2.58E-19	0.00E+00	0.00E+00
80	440	1.22E-19	0.00E+00	0.00E+00
81	445.5	5.76E-20	0.00E+00	0.00E+00
82	451	2.72E-20	0.00E+00	0.00E+00
83	456.5	1.29E-20	4.40E-24	1.21E-23
84	462	6.07E-21	2.37E-23	8.94E-23
85	467.5	2.87E-21	3.42E-23	2.49E-22
86	473	1.36E-21	3.91E-23	4.50E-22
87	478.5	6.40E-22	2.73E-23	6.33E-22
88	484	3.03E-22	1.29E-23	7.43E-22
89	489.5	1.43E-22	6.08E-24	7.95E-22
90	495	6.75E-23	2.87E-24	8.20E-22
91	500.5	3.19E-23	1.36E-24	8.32E-22
92	506	1.51E-23	6.42E-25	8.37E-22
93	511.5	7.12E-24	3.03E-25	8.40E-22
94	517	3.36E-24	1.43E-25	8.41E-22
95	522.5	1.59E-24	6.76E-26	8.42E-22
96	528	7.51E-25	3.20E-26	8.42E-22
97	533.5	3.55E-25	1.51E-26	8.42E-22
98	539	1.68E-25	7.13E-27	8.42E-22
99	544.5	7.92E-26	3.37E-27	8.42E-22
100	550	3.74E-26	1.59E-27	8.42E-22





Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	650

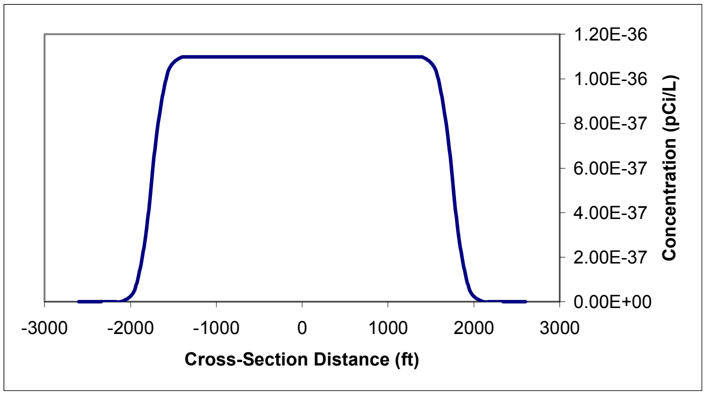


500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	1.24E-29
1	75	1.32E-29
2	150	1.38E-29
3	225	1.41E-29
4	300	1.42E-29
5	375	1.40E-29
6	450	1.32E-29
7	525	1.18E-29
8	600	1.02E-29
9	675	8.58E-30
10	750	7.05E-30
11	825	5.64E-30
12	900	4.38E-30
13	975	3.31E-30
14	1050	2.45E-30
15	1125	1.74E-30
16	1200	1.20E-30
17	1275	7.93E-31
18	1350	5.09E-31
19	1425	3.16E-31
20	1500	1.89E-31
21	1575	1.09E-31
22	1650	6.02E-32
23	1725	3.21E-32
24	1800	1.65E-32
25	1875	8.13E-33
26	1950	3.86E-33
27	2025	1.76E-33
28	2100	7.69E-34
29	2175	3.23E-34
30	2250	1.30E-34
31	2325	5.05E-35
32	2400	1.88E-35
33	2475	6.71E-36
34	2550	2.30E-36
35	2625	7.49E-37
36	2700	2.37E-37
37	2775	7.17E-38
38	2850	2.08E-38
39	2925	5.85E-39
40	3000	1.56E-39

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	650

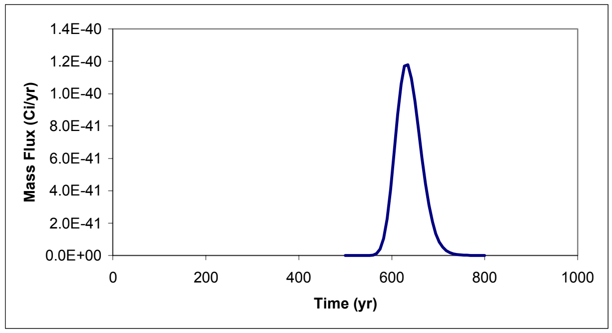


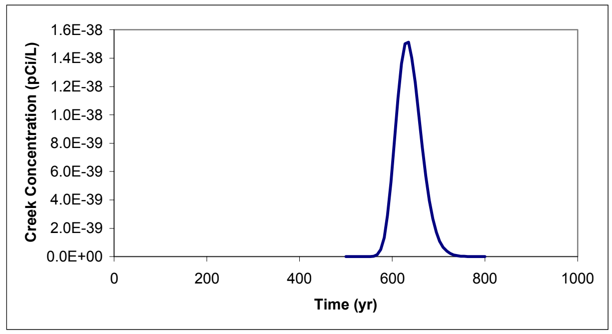
	y (ft)	C(x,y,t)
0	-2600	2.23E-48
1	-2470	2.10E-45
2	-2340	7.12E-43
3	-2210	8.52E-41
4	-2080	3.57E-39
5	-1950	5.39E-38
6	-1820	3.07E-37
7	-1690	7.58E-37
8	-1560	1.03E-36
9	-1430	1.09E-36
10	-1300	1.10E-36
11	-1170	1.10E-36
12	-1040	1.10E-36
13	-910	1.10E-36
14	-780	1.10E-36
15	-650	1.10E-36
16	-520	1.10E-36
17	-390	1.10E-36
18	-260	1.10E-36
19	-130	1.10E-36
20	0	1.10E-36
21	130	1.10E-36
22	260	1.10E-36
23	390	1.10E-36
24	520	1.10E-36
25	650	1.10E-36
26	780	1.10E-36
27	910	1.10E-36
28	1040	1.10E-36
29	1170	1.10E-36
30	1300	1.10E-36
31	1430	1.09E-36
32	1560	1.03E-36
33	1690	7.58E-37
34	1820	3.07E-37
35	1950	5.39E-38
36	2080	3.57E-39
37	2210	8.52E-41
38	2340	7.12E-43
39	2470	2.10E-45
40	2600	2.23E-48

Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	500
t_{max} (yr) =	800

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	500	0.00E+00	0.00E+00	0.00E+00
1	507.5	0.00E+00	0.00E+00	0.00E+00
2	515	0.00E+00	0.00E+00	0.00E+00
3	522.5	0.00E+00	0.00E+00	0.00E+00
4	530	0.00E+00	0.00E+00	0.00E+00
5	537.5	1.51E-46	5.66E-46	1.93E-44
6	545	4.28E-45	1.72E-44	5.49E-43
7	552.5	4.27E-44	1.94E-43	5.48E-42
8	560	2.68E-43	1.36E-42	3.44E-41
9	567.5	1.19E-42	6.83E-42	1.53E-40
10	575	3.98E-42	2.62E-41	5.11E-40
11	582.5	1.05E-41	8.06E-41	1.35E-39
12	590	2.26E-41	2.05E-40	2.90E-39
13	597.5	4.09E-41	4.43E-40	5.24E-39
14	605	6.39E-41	8.36E-40	8.19E-39
15	612.5	8.72E-41	1.40E-39	1.12E-38
16	620	1.06E-40	2.13E-39	1.36E-38
17	627.5	1.17E-40	2.96E-39	1.50E-38
18	635	1.18E-40	3.85E-39	1.51E-38
19	642.5	1.09E-40	4.70E-39	1.40E-38
20	650	9.57E-41	5.47E-39	1.23E-38
21	657.5	7.81E-41	6.12E-39	1.00E-38
22	665	6.02E-41	6.64E-39	7.72E-39
23	672.5	4.43E-41	7.03E-39	5.68E-39
24	680	3.09E-41	7.31E-39	3.97E-39
25	687.5	2.08E-41	7.51E-39	2.67E-39
26	695	1.35E-41	7.63E-39	1.73E-39
27	702.5	8.45E-42	7.72E-39	1.08E-39
28	710	5.15E-42	7.77E-39	6.60E-40
29	717.5	3.04E-42	7.80E-39	3.89E-40
30	725	1.74E-42	7.82E-39	2.23E-40
31	732.5	9.75E-43	7.83E-39	1.25E-40
32	740	5.35E-43	7.83E-39	6.86E-41
33	747.5	2.88E-43	7.83E-39	3.69E-41
34	755	1.52E-43	7.84E-39	1.95E-41
35	762.5	7.91E-44	7.84E-39	1.01E-41
36	770	4.04E-44	7.84E-39	5.18E-42
37	777.5	2.03E-44	7.84E-39	2.60E-42
38	785	9.98E-45	7.84E-39	1.28E-42
39	792.5	4.89E-45	7.84E-39	6.27E-43
40	800	2.37E-45	7.84E-39	3.04E-43





Tc^{99}

Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	1.20E+01	λ_D (yr^{-1})	0.0000
Δt_R (yr)	5	I_m (Ci/yr)	1
Δt_O (yr)	20		
$T_{1/2}$ (yr)	2.13E+05		

Summary

Total Flux to Water Table (Ci) =	**1.20E+01**
Total Flux to Creek (Ci) =	**1.20E+01**
Maximum Flux to Water Table (Ci/yr) =	**6.58E-01**
Maximum Flux to Creek (Ci/yr) =	**4.11E-01**
Maximum Creek Concentration (pCi/L) =	**5.27E+01**

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.1905488
f_L	1.00	I_{max} (Ci)	3
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^w (L/kg)	0.1		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	10.08
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	1.64
n	0.25	D_{xx}' (ft^2/yr)	13170.732
a_L (ft)	135	D_{yy}' (ft^2/yr)	1659
a_T (ft)	17	v_x' (ft/yr)	97.561
L (ft)	1000	c_o/M (ft^{-3})	7.92E-09
W (ft)	3500		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	0.1		

Creek Discharge

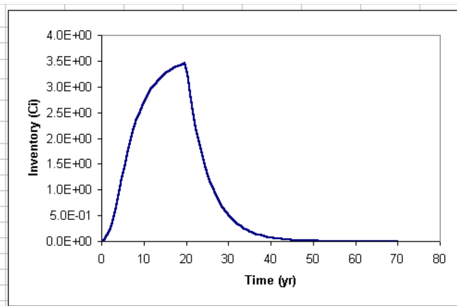
Q_c (m^3/yr)	7.80E+06

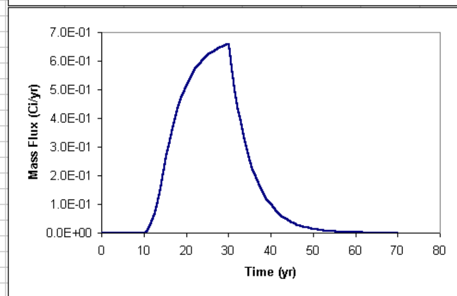
Integral Convergence Criteria

ε_1	0.01	**Local Concentration**
ε_2	0.1	**Creek Flux**

Inventory and Water Table Flux

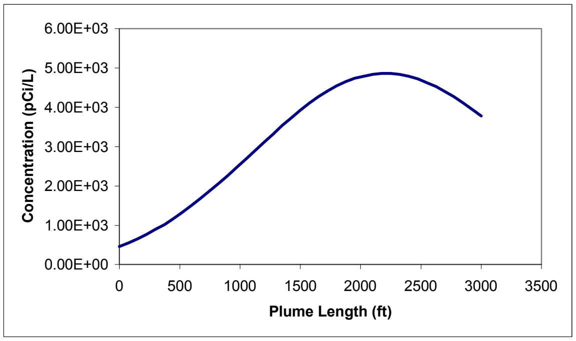
	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	70		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	0.7	3.22E-02	0.00E+00	0.00E+00
2	1.4	1.23E-01	0.00E+00	0.00E+00
3	2.1	2.66E-01	0.00E+00	0.00E+00
4	2.8	4.53E-01	0.00E+00	0.00E+00
5	3.5	6.81E-01	0.00E+00	0.00E+00
6	4.2	9.42E-01	0.00E+00	0.00E+00
7	4.9	1.23E+00	0.00E+00	0.00E+00
8	5.6	1.53E+00	0.00E+00	0.00E+00
9	6.3	1.79E+00	0.00E+00	0.00E+00
10	7	2.01E+00	0.00E+00	0.00E+00
11	7.7	2.21E+00	0.00E+00	0.00E+00
12	8.4	2.38E+00	0.00E+00	0.00E+00
13	9.1	2.54E+00	0.00E+00	0.00E+00
14	9.8	2.67E+00	0.00E+00	0.00E+00
15	10.5	2.79E+00	2.24E-03	7.86E-04
16	11.2	2.89E+00	1.53E-02	6.92E-03
17	11.9	2.98E+00	3.87E-02	2.58E-02
18	12.6	3.05E+00	7.11E-02	6.42E-02
19	13.3	3.12E+00	1.12E-01	1.28E-01
20	14	3.18E+00	1.59E-01	2.23E-01
21	14.7	3.23E+00	2.12E-01	3.53E-01
22	15.4	3.28E+00	2.70E-01	5.21E-01
23	16.1	3.32E+00	3.22E-01	7.28E-01
24	16.8	3.35E+00	3.67E-01	9.70E-01
25	17.5	3.38E+00	4.07E-01	1.24E+00
26	18.2	3.41E+00	4.42E-01	1.54E+00
27	18.9	3.43E+00	4.72E-01	1.86E+00
28	19.6	3.45E+00	4.99E-01	2.20E+00
29	20.3	3.27E+00	5.22E-01	2.55E+00
30	21	2.86E+00	5.43E-01	2.93E+00
31	21.7	2.51E+00	5.60E-01	3.31E+00
32	22.4	2.19E+00	5.76E-01	3.71E+00
33	23.1	1.92E+00	5.90E-01	4.12E+00
34	23.8	1.68E+00	6.02E-01	4.54E+00
35	24.5	1.47E+00	6.12E-01	4.96E+00
36	25.2	1.29E+00	6.21E-01	5.39E+00
37	25.9	1.13E+00	6.29E-01	5.83E+00
38	26.6	9.85E-01	6.36E-01	6.27E+00
39	27.3	8.62E-01	6.43E-01	6.72E+00
40	28	7.55E-01	6.48E-01	7.17E+00
41	28.7	6.60E-01	6.53E-01	7.63E+00
42	29.4	5.78E-01	6.57E-01	8.09E+00
43	30.1	5.06E-01	6.58E-01	8.55E+00
44	30.8	4.43E-01	5.76E-01	8.98E+00
45	31.5	3.87E-01	5.04E-01	9.36E+00
46	32.2	3.39E-01	4.41E-01	9.69E+00
47	32.9	2.97E-01	3.86E-01	9.98E+00
48	33.6	2.60E-01	3.38E-01	1.02E+01
49	34.3	2.27E-01	2.95E-01	1.05E+01
50	35	1.99E-01	2.59E-01	1.06E+01
51	35.7	1.74E-01	2.26E-01	1.08E+01
52	36.4	1.52E-01	1.98E-01	1.10E+01
53	37.1	1.33E-01	1.73E-01	1.11E+01
54	37.8	1.17E-01	1.52E-01	1.12E+01
55	38.5	1.02E-01	1.33E-01	1.13E+01
56	39.2	8.93E-02	1.16E-01	1.14E+01
57	39.9	7.81E-02	1.02E-01	1.15E+01
58	40.6	6.84E-02	8.90E-02	1.15E+01
59	41.3	5.99E-02	7.78E-02	1.16E+01
60	42	5.24E-02	6.81E-02	1.16E+01
61	42.7	4.58E-02	5.96E-02	1.17E+01
62	43.4	4.01E-02	5.22E-02	1.17E+01
63	44.1	3.51E-02	4.57E-02	1.18E+01
64	44.8	3.07E-02	4.00E-02	1.18E+01
65	45.5	2.69E-02	3.50E-02	1.18E+01
66	46.2	2.35E-02	3.06E-02	1.18E+01
67	46.9	2.06E-02	2.68E-02	1.19E+01
68	47.6	1.80E-02	2.34E-02	1.19E+01
69	48.3	1.58E-02	2.05E-02	1.19E+01
70	49	1.38E-02	1.79E-02	1.19E+01
71	49.7	1.21E-02	1.57E-02	1.19E+01
72	50.4	1.06E-02	1.37E-02	1.19E+01
73	51.1	9.25E-03	1.20E-02	1.19E+01
74	51.8	8.09E-03	1.05E-02	1.19E+01
75	52.5	7.08E-03	9.21E-03	1.20E+01
76	53.2	6.20E-03	8.06E-03	1.20E+01
77	53.9	5.42E-03	7.06E-03	1.20E+01
78	54.6	4.75E-03	6.17E-03	1.20E+01
79	55.3	4.15E-03	5.40E-03	1.20E+01
80	56	3.64E-03	4.73E-03	1.20E+01
81	56.7	3.18E-03	4.14E-03	1.20E+01
82	57.4	2.78E-03	3.62E-03	1.20E+01
83	58.1	2.44E-03	3.17E-03	1.20E+01
84	58.8	2.13E-03	2.77E-03	1.20E+01
85	59.5	1.87E-03	2.43E-03	1.20E+01
86	60.2	1.63E-03	2.12E-03	1.20E+01
87	60.9	1.43E-03	1.86E-03	1.20E+01
88	61.6	1.25E-03	1.63E-03	1.20E+01
89	62.3	1.09E-03	1.42E-03	1.20E+01
90	63	9.58E-04	1.25E-03	1.20E+01
91	63.7	8.38E-04	1.09E-03	1.20E+01
92	64.4	7.34E-04	9.54E-04	1.20E+01
93	65.1	6.42E-04	8.35E-04	1.20E+01
94	65.8	5.62E-04	7.31E-04	1.20E+01
95	66.5	4.92E-04	6.39E-04	1.20E+01
96	67.2	4.30E-04	5.60E-04	1.20E+01
97	67.9	3.76E-04	4.90E-04	1.20E+01
98	68.6	3.29E-04	4.29E-04	1.20E+01
99	69.3	2.88E-04	3.75E-04	1.20E+01
100	70	2.52E-04	3.28E-04	1.20E+01





Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	50

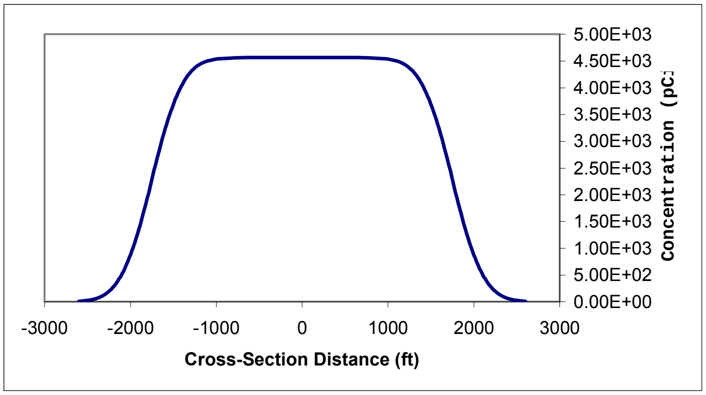


500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	4.60E+02
1	75	5.53E+02
2	150	6.54E+02
3	225	7.70E+02
4	300	8.98E+02
5	375	1.02E+03
6	450	1.17E+03
7	525	1.34E+03
8	600	1.51E+03
9	675	1.69E+03
10	750	1.87E+03
11	825	2.07E+03
12	900	2.27E+03
13	975	2.48E+03
14	1050	2.69E+03
15	1125	2.90E+03
16	1200	3.11E+03
17	1275	3.32E+03
18	1350	3.54E+03
19	1425	3.74E+03
20	1500	3.93E+03
21	1575	4.10E+03
22	1650	4.27E+03
23	1725	4.41E+03
24	1800	4.54E+03
25	1875	4.65E+03
26	1950	4.74E+03
27	2025	4.79E+03
28	2100	4.83E+03
29	2175	4.86E+03
30	2250	4.86E+03
31	2325	4.84E+03
32	2400	4.79E+03
33	2475	4.72E+03
34	2550	4.63E+03
35	2625	4.53E+03
36	2700	4.40E+03
37	2775	4.26E+03
38	2850	4.11E+03
39	2925	3.95E+03
40	3000	3.78E+03

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	50

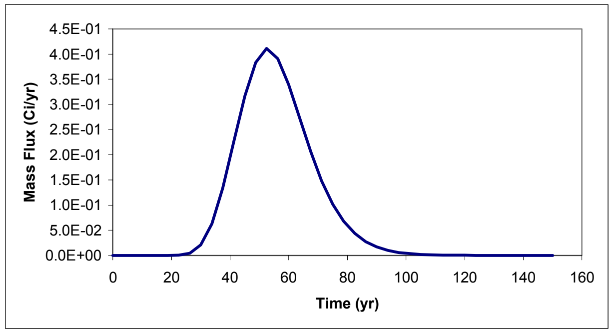


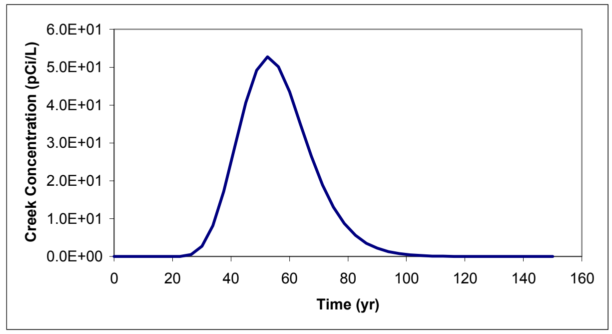
	y (ft)	C(x,y,t)
0	-2600	9.54E+00
1	-2470	3.26E+01
2	-2340	9.75E+01
3	-2210	2.54E+02
4	-2080	5.70E+02
5	-1950	1.10E+03
6	-1820	1.84E+03
7	-1690	2.66E+03
8	-1560	3.41E+03
9	-1430	3.96E+03
10	-1300	4.29E+03
11	-1170	4.46E+03
12	-1040	4.53E+03
13	-910	4.55E+03
14	-780	4.56E+03
15	-650	4.56E+03
16	-520	4.56E+03
17	-390	4.56E+03
18	-260	4.56E+03
19	-130	4.56E+03
20	0	4.56E+03
21	130	4.56E+03
22	260	4.56E+03
23	390	4.56E+03
24	520	4.56E+03
25	650	4.56E+03
26	780	4.56E+03
27	910	4.55E+03
28	1040	4.53E+03
29	1170	4.46E+03
30	1300	4.29E+03
31	1430	3.96E+03
32	1560	3.41E+03
33	1690	2.66E+03
34	1820	1.84E+03
35	1950	1.10E+03
36	2080	5.70E+02
37	2210	2.54E+02
38	2340	9.75E+01
39	2470	3.26E+01
40	2600	9.54E+00

Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	0
t_{max} (yr) =	150

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	0	0.00E+00	0.00E+00	0.00E+00
1	3.75	0.00E+00	0.00E+00	0.00E+00
2	7.5	0.00E+00	0.00E+00	0.00E+00
3	11.25	0.00E+00	0.00E+00	0.00E+00
4	15	1.14E-10	2.14E-10	1.46E-08
5	18.75	3.18E-06	5.96E-06	4.08E-04
6	22.5	2.99E-04	5.73E-04	3.83E-02
7	26.25	4.04E-03	8.71E-03	5.18E-01
8	30	2.11E-02	5.58E-02	2.70E+00
9	33.75	6.32E-02	2.14E-01	8.11E+00
10	37.5	1.34E-01	5.84E-01	1.72E+01
11	41.25	2.25E-01	1.26E+00	2.88E+01
12	45	3.17E-01	2.27E+00	4.06E+01
13	48.75	3.83E-01	3.58E+00	4.91E+01
14	52.5	4.11E-01	5.07E+00	5.27E+01
15	56.25	3.91E-01	6.58E+00	5.01E+01
16	60	3.39E-01	7.95E+00	4.35E+01
17	63.75	2.72E-01	9.09E+00	3.49E+01
18	67.5	2.07E-01	9.99E+00	2.65E+01
19	71.25	1.48E-01	1.07E+01	1.89E+01
20	75	1.02E-01	1.11E+01	1.31E+01
21	78.75	6.79E-02	1.14E+01	8.71E+00
22	82.5	4.38E-02	1.17E+01	5.62E+00
23	86.25	2.73E-02	1.18E+01	3.50E+00
24	90	1.70E-02	1.19E+01	2.18E+00
25	93.75	1.02E-02	1.19E+01	1.31E+00
26	97.5	6.08E-03	1.20E+01	7.80E-01
27	101.25	3.58E-03	1.20E+01	4.58E-01
28	105	2.08E-03	1.20E+01	2.66E-01
29	108.75	1.19E-03	1.20E+01	1.53E-01
30	112.5	6.79E-04	1.20E+01	8.71E-02
31	116.25	3.83E-04	1.20E+01	4.92E-02
32	120	2.15E-04	1.20E+01	2.75E-02
33	123.75	1.20E-04	1.20E+01	1.53E-02
34	127.5	6.62E-05	1.20E+01	8.49E-03
35	131.25	3.63E-05	1.20E+01	4.66E-03
36	135	2.00E-05	1.20E+01	2.56E-03
37	138.75	1.08E-05	1.20E+01	1.39E-03
38	142.5	5.81E-06	1.20E+01	7.45E-04
39	146.25	3.17E-06	1.20E+01	4.06E-04
40	150	1.71E-06	1.20E+01	2.19E-04





I^{129}

Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	1.06E+01	λ_D (yr^{-1})	0.0000
Δt_R (yr)	5	I_m (Ci/yr)	1
Δt_O (yr)	20		
$T_{1/2}$ (yr)	1.57E+07		

Summary

Total Flux to Water Table (Ci) =	1.06E+01
Total Flux to Creek (Ci) =	1.06E+01
Maximum Flux to Water Table (Ci/yr) =	3.08E-01
Maximum Flux to Creek (Ci/yr) =	8.98E-02
Maximum Creek Concentration (pCi/L) =	1.15E+01

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.0422297
f_L	1.00	I_{max} (Ci)	7
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^W (L/kg)	1		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	50.4
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	7.4
n	0.25	D_{xx}' (ft^2/yr)	2918.9189
a_L (ft)	135	D_{yy}' (ft^2/yr)	368
a_T (ft)	17	v_x' (ft/yr)	21.622
L (ft)	1000	c_o/M (ft^{-3})	1.76E-09
W (ft)	3500		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	1		

Creek Discharge

Q_c (m^3/yr)	7.80E+06

Integral Convergence Criteria

ε_1	0.01	Local Concentration
ε_2	0.1	Creek Flux

Inventory and Water Table Flux

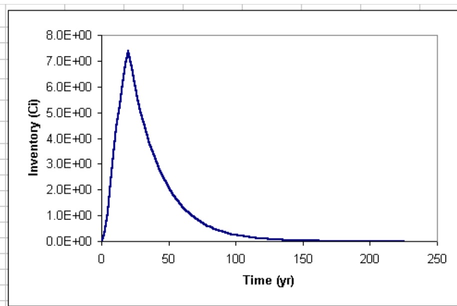
Inventory (Ci)

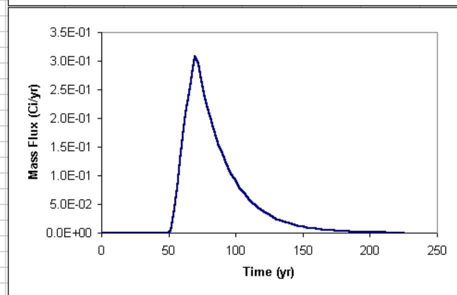
t_{min} (yr): 0

t_{max} (yr): 225

Water Table Flux (Ci/yr)

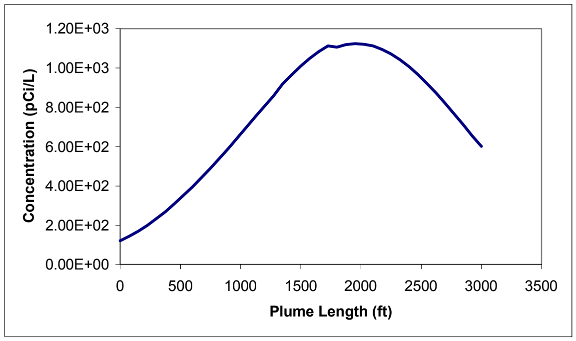
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	2.25	2.97E-01	0.00E+00	0.00E+00
2	4.5	1.15E+00	0.00E+00	0.00E+00
3	6.75	2.33E+00	0.00E+00	0.00E+00
4	9	3.42E+00	0.00E+00	0.00E+00
5	11.25	4.41E+00	0.00E+00	0.00E+00
6	13.5	5.31E+00	0.00E+00	0.00E+00
7	15.75	6.13E+00	0.00E+00	0.00E+00
8	18	6.88E+00	0.00E+00	0.00E+00
9	20.25	7.40E+00	0.00E+00	0.00E+00
10	22.5	6.73E+00	0.00E+00	0.00E+00
11	24.75	6.12E+00	0.00E+00	0.00E+00
12	27	5.57E+00	0.00E+00	0.00E+00
13	29.25	5.06E+00	0.00E+00	0.00E+00
14	31.5	4.60E+00	0.00E+00	0.00E+00
15	33.75	4.19E+00	0.00E+00	0.00E+00
16	36	3.81E+00	0.00E+00	0.00E+00
17	38.25	3.46E+00	0.00E+00	0.00E+00
18	40.5	3.15E+00	0.00E+00	0.00E+00
19	42.75	2.86E+00	0.00E+00	0.00E+00
20	45	2.60E+00	0.00E+00	0.00E+00
21	47.25	2.37E+00	0.00E+00	0.00E+00
22	49.5	2.15E+00	0.00E+00	0.00E+00
23	51.75	1.96E+00	4.57E-03	5.15E-03
24	54	1.78E+00	3.15E-02	4.58E-02
25	56.25	1.62E+00	7.89E-02	1.70E-01
26	58.5	1.47E+00	1.27E-01	4.01E-01
27	60.75	1.34E+00	1.70E-01	7.35E-01
28	63	1.22E+00	2.10E-01	1.16E+00
29	65.25	1.11E+00	2.45E-01	1.67E+00
30	67.5	1.01E+00	2.78E-01	2.26E+00
31	69.75	9.15E-01	3.08E-01	2.92E+00
32	72	8.32E-01	2.95E-01	3.60E+00
33	74.25	7.57E-01	2.68E-01	4.24E+00
34	76.5	6.88E-01	2.44E-01	4.81E+00
35	78.75	6.26E-01	2.22E-01	5.34E+00
36	81	5.69E-01	2.02E-01	5.81E+00
37	83.25	5.18E-01	1.84E-01	6.25E+00
38	85.5	4.71E-01	1.67E-01	6.64E+00
39	87.75	4.28E-01	1.52E-01	7.00E+00
40	90	3.89E-01	1.38E-01	7.33E+00
41	92.25	3.54E-01	1.26E-01	7.62E+00
42	94.5	3.22E-01	1.14E-01	7.89E+00
43	96.75	2.93E-01	1.04E-01	8.14E+00
44	99	2.66E-01	9.44E-02	8.36E+00
45	101.25	2.42E-01	8.59E-02	8.56E+00
46	103.5	2.20E-01	7.81E-02	8.75E+00
47	105.75	2.00E-01	7.10E-02	8.92E+00
48	108	1.82E-01	6.46E-02	9.07E+00
49	110.25	1.65E-01	5.87E-02	9.21E+00
50	112.5	1.50E-01	5.34E-02	9.33E+00
51	114.75	1.37E-01	4.85E-02	9.45E+00
52	117	1.24E-01	4.41E-02	9.55E+00
53	119.25	1.13E-01	4.01E-02	9.65E+00
54	121.5	1.03E-01	3.65E-02	9.73E+00
55	123.75	9.36E-02	3.32E-02	9.81E+00
56	126	8.51E-02	3.02E-02	9.88E+00
57	128.25	7.74E-02	2.75E-02	9.95E+00
58	130.5	7.04E-02	2.50E-02	1.00E+01
59	132.75	6.40E-02	2.27E-02	1.01E+01
60	135	5.82E-02	2.06E-02	1.01E+01
61	137.25	5.29E-02	1.88E-02	1.02E+01
62	139.5	4.81E-02	1.71E-02	1.02E+01
63	141.75	4.38E-02	1.55E-02	1.02E+01
64	144	3.98E-02	1.41E-02	1.03E+01
65	146.25	3.62E-02	1.28E-02	1.03E+01
66	148.5	3.29E-02	1.17E-02	1.03E+01
67	150.75	2.99E-02	1.06E-02	1.03E+01
68	153	2.72E-02	9.65E-03	1.04E+01
69	155.25	2.47E-02	8.78E-03	1.04E+01
70	157.5	2.25E-02	7.98E-03	1.04E+01
71	159.75	2.05E-02	7.26E-03	1.04E+01
72	162	1.86E-02	6.60E-03	1.04E+01
73	164.25	1.69E-02	6.00E-03	1.05E+01
74	166.5	1.54E-02	5.46E-03	1.05E+01
75	168.75	1.40E-02	4.96E-03	1.05E+01
76	171	1.27E-02	4.51E-03	1.05E+01
77	173.25	1.16E-02	4.10E-03	1.05E+01
78	175.5	1.05E-02	3.73E-03	1.05E+01
79	177.75	9.57E-03	3.39E-03	1.05E+01
80	180	8.70E-03	3.09E-03	1.05E+01
81	182.25	7.91E-03	2.81E-03	1.05E+01
82	184.5	7.19E-03	2.55E-03	1.05E+01
83	186.75	6.54E-03	2.32E-03	1.05E+01
84	189	5.95E-03	2.11E-03	1.05E+01
85	191.25	5.41E-03	1.92E-03	1.06E+01
86	193.5	4.92E-03	1.75E-03	1.06E+01
87	195.75	4.47E-03	1.59E-03	1.06E+01
88	198	4.07E-03	1.44E-03	1.06E+01
89	200.25	3.70E-03	1.31E-03	1.06E+01
90	202.5	3.36E-03	1.19E-03	1.06E+01
91	204.75	3.06E-03	1.09E-03	1.06E+01
92	207	2.78E-03	9.87E-04	1.06E+01
93	209.25	2.53E-03	8.97E-04	1.06E+01
94	211.5	2.30E-03	8.16E-04	1.06E+01
95	213.75	2.09E-03	7.42E-04	1.06E+01
96	216	1.90E-03	6.75E-04	1.06E+01
97	218.25	1.73E-03	6.14E-04	1.06E+01
98	220.5	1.57E-03	5.58E-04	1.06E+01
99	222.75	1.43E-03	5.07E-04	1.06E+01
100	225	1.30E-03	4.61E-04	1.06E+01





Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	175

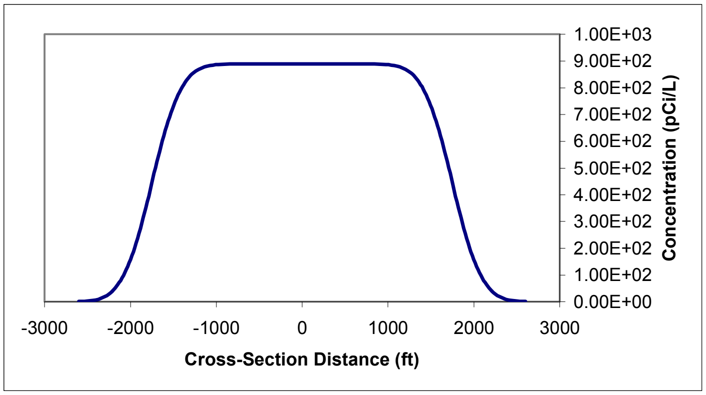


500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	1.20E+02
1	75	1.44E+02
2	150	1.70E+02
3	225	1.99E+02
4	300	2.33E+02
5	375	2.69E+02
6	450	3.10E+02
7	525	3.51E+02
8	600	3.95E+02
9	675	4.42E+02
10	750	4.90E+02
11	825	5.40E+02
12	900	5.92E+02
13	975	6.45E+02
14	1050	7.00E+02
15	1125	7.54E+02
16	1200	8.07E+02
17	1275	8.58E+02
18	1350	9.19E+02
19	1425	9.66E+02
20	1500	1.01E+03
21	1575	1.05E+03
22	1650	1.08E+03
23	1725	1.11E+03
24	1800	1.11E+03
25	1875	1.12E+03
26	1950	1.12E+03
27	2025	1.12E+03
28	2100	1.11E+03
29	2175	1.10E+03
30	2250	1.07E+03
31	2325	1.04E+03
32	2400	1.01E+03
33	2475	9.66E+02
34	2550	9.21E+02
35	2625	8.72E+02
36	2700	8.20E+02
37	2775	7.66E+02
38	2850	7.11E+02
39	2925	6.56E+02
40	3000	6.01E+02

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	175

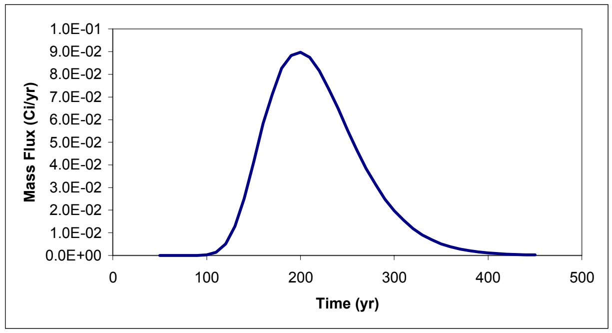


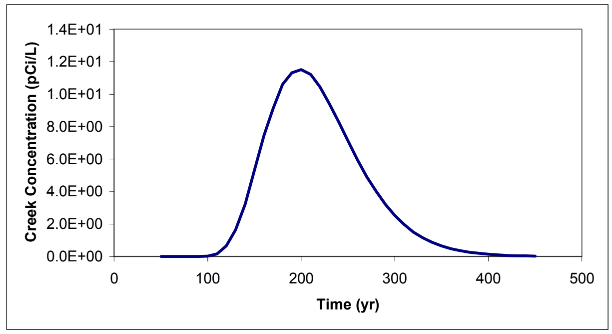
	y (ft)	C(x,y,t)
0	-2600	8.42E-01
1	-2470	3.66E+00
2	-2340	1.32E+01
3	-2210	3.94E+01
4	-2080	9.80E+01
5	-1950	2.03E+02
6	-1820	3.53E+02
7	-1690	5.23E+02
8	-1560	6.76E+02
9	-1430	7.84E+02
10	-1300	8.46E+02
11	-1170	8.74E+02
12	-1040	8.84E+02
13	-910	8.88E+02
14	-780	8.88E+02
15	-650	8.88E+02
16	-520	8.88E+02
17	-390	8.89E+02
18	-260	8.89E+02
19	-130	8.89E+02
20	0	8.89E+02
21	130	8.89E+02
22	260	8.89E+02
23	390	8.89E+02
24	520	8.88E+02
25	650	8.88E+02
26	780	8.88E+02
27	910	8.88E+02
28	1040	8.84E+02
29	1170	8.74E+02
30	1300	8.46E+02
31	1430	7.84E+02
32	1560	6.76E+02
33	1690	5.23E+02
34	1820	3.53E+02
35	1950	2.03E+02
36	2080	9.80E+01
37	2210	3.94E+01
38	2340	1.32E+01
39	2470	3.66E+00
40	2600	8.42E-01

Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	50
t_{max} (yr) =	450

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	50	0.00E+00	0.00E+00	0.00E+00
1	60	5.63E-22	2.81E-21	7.22E-20
2	70	2.42E-11	1.21E-10	3.11E-09
3	80	1.40E-07	6.99E-07	1.79E-05
4	90	1.31E-05	6.69E-05	1.68E-03
5	100	2.15E-04	1.21E-03	2.76E-02
6	110	1.39E-03	9.23E-03	1.78E-01
7	120	5.11E-03	4.17E-02	6.55E-01
8	130	1.29E-02	1.32E-01	1.65E+00
9	140	2.52E-02	3.22E-01	3.23E+00
10	150	4.14E-02	6.55E-01	5.31E+00
11	160	5.82E-02	1.15E+00	7.46E+00
12	170	7.13E-02	1.80E+00	9.14E+00
13	180	8.27E-02	2.57E+00	1.06E+01
14	190	8.83E-02	3.42E+00	1.13E+01
15	200	8.98E-02	4.32E+00	1.15E+01
16	210	8.74E-02	5.20E+00	1.12E+01
17	220	8.14E-02	6.05E+00	1.04E+01
18	230	7.36E-02	6.82E+00	9.43E+00
19	240	6.48E-02	7.51E+00	8.31E+00
20	250	5.55E-02	8.11E+00	7.11E+00
21	260	4.66E-02	8.62E+00	5.97E+00
22	270	3.84E-02	9.05E+00	4.92E+00
23	280	3.13E-02	9.40E+00	4.01E+00
24	290	2.49E-02	9.68E+00	3.19E+00
25	300	1.98E-02	9.90E+00	2.54E+00
26	310	1.55E-02	1.01E+01	1.99E+00
27	320	1.18E-02	1.02E+01	1.51E+00
28	330	9.02E-03	1.03E+01	1.16E+00
29	340	6.84E-03	1.04E+01	8.77E-01
30	350	5.15E-03	1.05E+01	6.60E-01
31	360	3.85E-03	1.05E+01	4.94E-01
32	370	2.87E-03	1.05E+01	3.67E-01
33	380	2.12E-03	1.06E+01	2.71E-01
34	390	1.54E-03	1.06E+01	1.98E-01
35	400	1.13E-03	1.06E+01	1.45E-01
36	410	8.21E-04	1.06E+01	1.05E-01
37	420	5.96E-04	1.06E+01	7.64E-02
38	430	4.31E-04	1.06E+01	5.52E-02
39	440	3.10E-04	1.06E+01	3.98E-02
40	450	2.23E-04	1.06E+01	2.86E-02



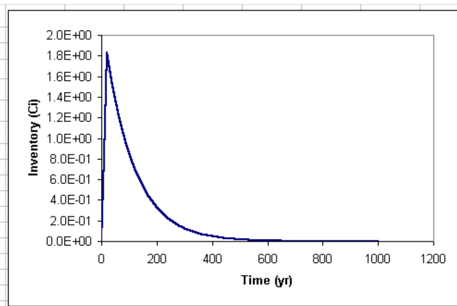


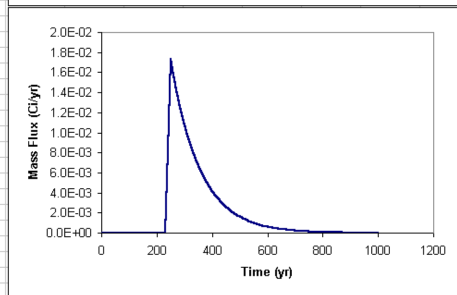
Np^{237}

	A	B	C	D	E	F	G	H	I	J	K
1											
2		***Groundwater Transport - SRS ORWBG***									
3											
4		***Delivered Inventory and Nulide Decay***					***Summary***				
5		**I_o (Ci)**	**1.99E+00**	λ_D (yr^{-1})	0.0000		**Total Flux to Water Table (Ci) =**				**1.99E+00**
6		**Δt_R (yr)**	**5**	I_m (Ci/yr)	0		**Total Flux to Creek (Ci) =**				**1.99E+00**
7		**Δt_O (yr)**	**20**				**Maximum Flux to Water Table (Ci/yr) =**				**1.73E-02**
8		**$T_{1/2}$ (yr)**	**2.14E+06**				**Maximum Flux to Creek (Ci/yr) =**				**3.79E-03**
9							**Maximum Creek Concentration (pCi/L) =**				**4.86E-01**
10		***Leaching***									
11		**q_f (ft/yr)**	**1.25**	λ_L (yr^{-1})	0.0094697						
12		**f_L**	**1.00**	I_{max} (Ci)	2						
13		**θ_{waste}**	**0.25**								
14		**ρ_{waste} (kg/L)**	**1.6**								
15		**K_d^w (L/kg)**	**5**								
16		**L_{waste} (ft)**	**16**								
17											
18		***Vadose Zone***									
19		**L_{vz} (ft)**	**35**	Δt_{vz} (yr)	229.6						
20		**θ_{vz}**	**0.2**								
21											
22		***Aquifer Parameters***									
23		**q_x (ft/yr)**	**40**	R	33						
24		**n**	**0.25**	D_{xx}' (ft^2/yr)	654.54545						
25		**a_L (ft)**	**135**	D_{yy}' (ft^2/yr)	82						
26		**a_T (ft)**	**17**	v_x' (ft/yr)	4.848						
27		**L (ft)**	**1000**	c_o/M (ft^{-3})	3.94E-10						
28		**W (ft)**	**3500**								
29		**H (ft)**	**22**								
30		**ρ_b (kg/L)**	**1.6**								
31		**K_d (L/kg)**	**5**								
32											
33		***Creek Discharge***									
34		**Q_c (m^3/yr)**	**7.80E+06**								
35											
36		***Integral Convergence Criteria***									
37		**ε_1**	**0.01**	**Local Concentration**							
38		**ε_2**	**0.1**	**Creek Flux**							

Inventory and Water Table Flux

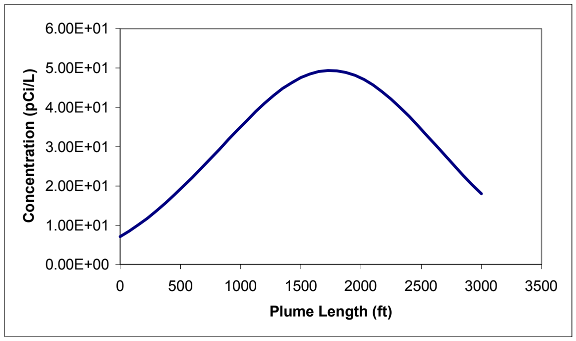
	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	1000		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	10	8.22E-01	0.00E+00	0.00E+00
2	20	1.83E+00	0.00E+00	0.00E+00
3	30	1.67E+00	0.00E+00	0.00E+00
4	40	1.52E+00	0.00E+00	0.00E+00
5	50	1.38E+00	0.00E+00	0.00E+00
6	60	1.25E+00	0.00E+00	0.00E+00
7	70	1.14E+00	0.00E+00	0.00E+00
8	80	1.04E+00	0.00E+00	0.00E+00
9	90	9.45E-01	0.00E+00	0.00E+00
10	100	8.59E-01	0.00E+00	0.00E+00
11	110	7.82E-01	0.00E+00	0.00E+00
12	120	7.11E-01	0.00E+00	0.00E+00
13	130	6.47E-01	0.00E+00	0.00E+00
14	140	5.88E-01	0.00E+00	0.00E+00
15	150	5.35E-01	0.00E+00	0.00E+00
16	160	4.87E-01	0.00E+00	0.00E+00
17	170	4.43E-01	0.00E+00	0.00E+00
18	180	4.03E-01	0.00E+00	0.00E+00
19	190	3.66E-01	0.00E+00	0.00E+00
20	200	3.33E-01	0.00E+00	0.00E+00
21	210	3.03E-01	0.00E+00	0.00E+00
22	220	2.76E-01	0.00E+00	0.00E+00
23	230	2.51E-01	1.72E-05	8.60E-05
24	240	2.28E-01	8.19E-03	4.11E-02
25	250	2.08E-01	1.73E-02	1.68E-01
26	260	1.89E-01	1.57E-02	3.34E-01
27	270	1.72E-01	1.43E-02	4.84E-01
28	280	1.56E-01	1.30E-02	6.20E-01
29	290	1.42E-01	1.18E-02	7.45E-01
30	300	1.29E-01	1.08E-02	8.58E-01
31	310	1.18E-01	9.80E-03	9.60E-01
32	320	1.07E-01	8.91E-03	1.05E+00
33	330	9.73E-02	8.11E-03	1.14E+00
34	340	8.85E-02	7.37E-03	1.22E+00
35	350	8.05E-02	6.71E-03	1.29E+00
36	360	7.32E-02	6.10E-03	1.35E+00
37	370	6.66E-02	5.55E-03	1.41E+00
38	380	6.06E-02	5.05E-03	1.46E+00
39	390	5.51E-02	4.59E-03	1.51E+00
40	400	5.02E-02	4.18E-03	1.55E+00
41	410	4.56E-02	3.80E-03	1.59E+00
42	420	4.15E-02	3.46E-03	1.63E+00
43	430	3.77E-02	3.14E-03	1.66E+00
44	440	3.43E-02	2.86E-03	1.69E+00
45	450	3.12E-02	2.60E-03	1.72E+00
46	460	2.84E-02	2.37E-03	1.75E+00
47	470	2.58E-02	2.15E-03	1.77E+00
48	480	2.35E-02	1.96E-03	1.79E+00
49	490	2.14E-02	1.78E-03	1.81E+00
50	500	1.95E-02	1.62E-03	1.82E+00
51	510	1.77E-02	1.47E-03	1.84E+00
52	520	1.61E-02	1.34E-03	1.85E+00
53	530	1.46E-02	1.22E-03	1.87E+00
54	540	1.33E-02	1.11E-03	1.88E+00
55	550	1.21E-02	1.01E-03	1.89E+00
56	560	1.10E-02	9.18E-04	1.90E+00
57	570	1.00E-02	8.35E-04	1.91E+00
58	580	9.12E-03	7.60E-04	1.92E+00
59	590	8.30E-03	6.91E-04	1.92E+00
60	600	7.55E-03	6.29E-04	1.93E+00
61	610	6.86E-03	5.72E-04	1.94E+00
62	620	6.24E-03	5.20E-04	1.94E+00
63	630	5.68E-03	4.73E-04	1.95E+00
64	640	5.17E-03	4.30E-04	1.95E+00
65	650	4.70E-03	3.91E-04	1.95E+00
66	660	4.28E-03	3.56E-04	1.96E+00
67	670	3.89E-03	3.24E-04	1.96E+00
68	680	3.54E-03	2.95E-04	1.96E+00
69	690	3.22E-03	2.68E-04	1.97E+00
70	700	2.93E-03	2.44E-04	1.97E+00
71	710	2.66E-03	2.22E-04	1.97E+00
72	720	2.42E-03	2.02E-04	1.97E+00
73	730	2.20E-03	1.84E-04	1.98E+00
74	740	2.00E-03	1.67E-04	1.98E+00
75	750	1.82E-03	1.52E-04	1.98E+00
76	760	1.66E-03	1.38E-04	1.98E+00
77	770	1.51E-03	1.26E-04	1.98E+00
78	780	1.37E-03	1.14E-04	1.98E+00
79	790	1.25E-03	1.04E-04	1.98E+00
80	800	1.14E-03	9.46E-05	1.99E+00
81	810	1.03E-03	8.60E-05	1.99E+00
82	820	9.40E-04	7.83E-05	1.99E+00
83	830	8.55E-04	7.12E-05	1.99E+00
84	840	7.77E-04	6.48E-05	1.99E+00
85	850	7.07E-04	5.89E-05	1.99E+00
86	860	6.43E-04	5.36E-05	1.99E+00
87	870	5.85E-04	4.87E-05	1.99E+00
88	880	5.32E-04	4.43E-05	1.99E+00
89	890	4.84E-04	4.03E-05	1.99E+00
90	900	4.40E-04	3.67E-05	1.99E+00
91	910	4.01E-04	3.34E-05	1.99E+00
92	920	3.64E-04	3.04E-05	1.99E+00
93	930	3.32E-04	2.76E-05	1.99E+00
94	940	3.02E-04	2.51E-05	1.99E+00
95	950	2.74E-04	2.28E-05	1.99E+00
96	960	2.50E-04	2.08E-05	1.99E+00
97	970	2.27E-04	1.89E-05	1.99E+00
98	980	2.06E-04	1.72E-05	1.99E+00
99	990	1.88E-04	1.56E-05	1.99E+00
100	1000	1.71E-04	1.42E-05	1.99E+00





Plume Profile

x_{min} (ft) =	**0**
x_{max} (ft) =	**3000**
y (ft) =	**0**
t (yr) =	**700**

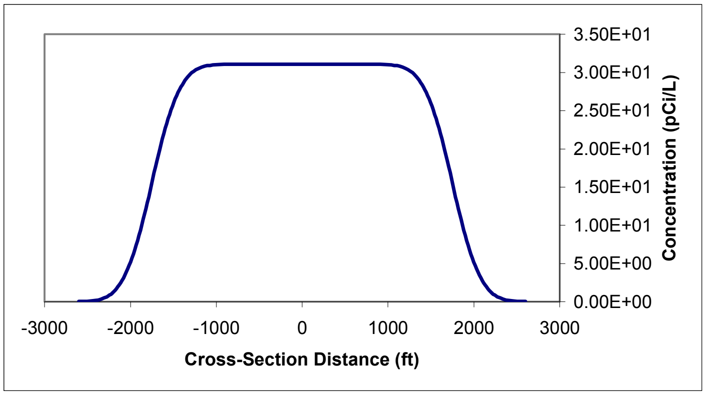


500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	7.11E+00
1	75	8.51E+00
2	150	1.01E+01
3	225	1.18E+01
4	300	1.37E+01
5	375	1.57E+01
6	450	1.78E+01
7	525	1.99E+01
8	600	2.22E+01
9	675	2.45E+01
10	750	2.69E+01
11	825	2.94E+01
12	900	3.18E+01
13	975	3.42E+01
14	1050	3.66E+01
15	1125	3.89E+01
16	1200	4.11E+01
17	1275	4.30E+01
18	1350	4.48E+01
19	1425	4.63E+01
20	1500	4.76E+01
21	1575	4.85E+01
22	1650	4.91E+01
23	1725	4.94E+01
24	1800	4.93E+01
25	1875	4.89E+01
26	1950	4.81E+01
27	2025	4.71E+01
28	2100	4.57E+01
29	2175	4.40E+01
30	2250	4.21E+01
31	2325	4.00E+01
32	2400	3.77E+01
33	2475	3.53E+01
34	2550	3.28E+01
35	2625	3.02E+01
36	2700	2.77E+01
37	2775	2.51E+01
38	2850	2.27E+01
39	2925	2.03E+01
40	3000	1.80E+01

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	700

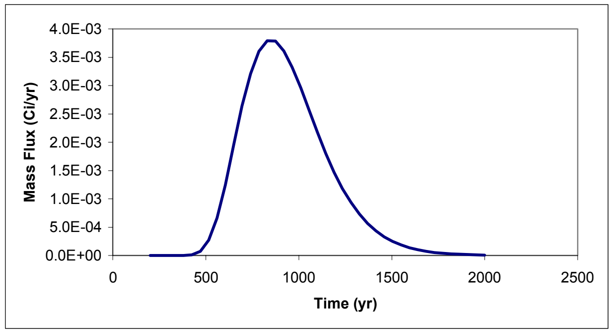


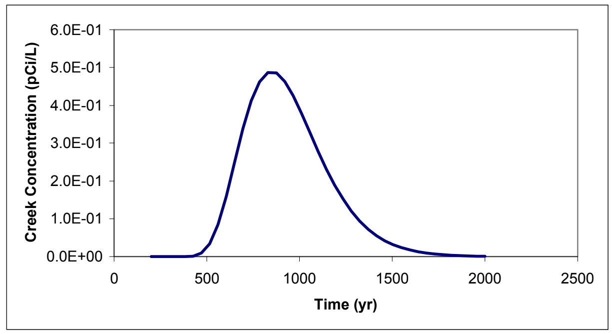
	y (ft)	C(x,y,t)
0	-2600	1.73E-02
1	-2470	8.78E-02
2	-2340	3.55E-01
3	-2210	1.16E+00
4	-2080	3.11E+00
5	-1950	6.78E+00
6	-1820	1.22E+01
7	-1690	1.84E+01
8	-1560	2.39E+01
9	-1430	2.78E+01
10	-1300	2.98E+01
11	-1170	3.07E+01
12	-1040	3.10E+01
13	-910	3.11E+01
14	-780	3.11E+01
15	-650	3.11E+01
16	-520	3.11E+01
17	-390	3.11E+01
18	-260	3.11E+01
19	-130	3.11E+01
20	0	3.11E+01
21	130	3.11E+01
22	260	3.11E+01
23	390	3.11E+01
24	520	3.11E+01
25	650	3.11E+01
26	780	3.11E+01
27	910	3.11E+01
28	1040	3.10E+01
29	1170	3.07E+01
30	1300	2.98E+01
31	1430	2.78E+01
32	1560	2.39E+01
33	1690	1.84E+01
34	1820	1.22E+01
35	1950	6.78E+00
36	2080	3.11E+00
37	2210	1.16E+00
38	2340	3.55E-01
39	2470	8.78E-02
40	2600	1.73E-02

Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	200
t_{max} (yr) =	2000

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	200	0.00E+00	0.00E+00	0.00E+00
1	245	0.00E+00	0.00E+00	0.00E+00
2	290	4.37E-16	9.83E-15	5.60E-14
3	335	9.56E-10	2.15E-08	1.23E-07
4	380	4.01E-07	9.07E-06	5.14E-05
5	425	1.05E-05	2.54E-04	1.34E-03
6	470	7.37E-05	2.15E-03	9.44E-03
7	515	2.70E-04	9.88E-03	3.46E-02
8	560	6.62E-04	3.08E-02	8.49E-02
9	605	1.24E-03	7.37E-02	1.59E-01
10	650	1.95E-03	1.46E-01	2.50E-01
11	695	2.64E-03	2.49E-01	3.39E-01
12	740	3.21E-03	3.81E-01	4.12E-01
13	785	3.61E-03	5.34E-01	4.62E-01
14	830	3.79E-03	7.01E-01	4.86E-01
15	875	3.79E-03	8.71E-01	4.86E-01
16	920	3.61E-03	1.04E+00	4.63E-01
17	965	3.32E-03	1.19E+00	4.26E-01
18	1010	2.96E-03	1.33E+00	3.79E-01
19	1055	2.57E-03	1.46E+00	3.29E-01
20	1100	2.18E-03	1.57E+00	2.79E-01
21	1145	1.80E-03	1.66E+00	2.31E-01
22	1190	1.47E-03	1.73E+00	1.89E-01
23	1235	1.18E-03	1.79E+00	1.52E-01
24	1280	9.38E-04	1.84E+00	1.20E-01
25	1325	7.35E-04	1.87E+00	9.42E-02
26	1370	5.65E-04	1.90E+00	7.24E-02
27	1415	4.33E-04	1.93E+00	5.55E-02
28	1460	3.28E-04	1.94E+00	4.21E-02
29	1505	2.47E-04	1.96E+00	3.17E-02
30	1550	1.85E-04	1.97E+00	2.37E-02
31	1595	1.37E-04	1.97E+00	1.76E-02
32	1640	1.01E-04	1.98E+00	1.30E-02
33	1685	7.39E-05	1.98E+00	9.47E-03
34	1730	5.40E-05	1.99E+00	6.92E-03
35	1775	3.93E-05	1.99E+00	5.03E-03
36	1820	2.84E-05	1.99E+00	3.65E-03
37	1865	2.05E-05	1.99E+00	2.63E-03
38	1910	1.47E-05	1.99E+00	1.89E-03
39	1955	1.06E-05	1.99E+00	1.35E-03
40	2000	7.54E-06	1.99E+00	9.66E-04





C^d

Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	1.59E+03	λ_D (yr^{-1})	0.0000
Δt_R (yr)	5	I_m (Ci/yr)	91
Δt_O (yr)	20		
$T_{1/2}$ (yr)	1.00E+10		

Summary

Total Flux to Water Table (Ci) =	1.58E+03
Total Flux to Creek (Ci) =	1.59E+03
Maximum Flux to Water Table (Ci/yr) =	1.13E+01
Maximum Flux to Creek (Ci/yr) =	2.55E+00
Maximum Creek Concentration (pCi/L) =	3.27E+02

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.0079315
f_L	1.00	I_{max} (Ci)	1486
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^w (L/kg)	6		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	274.4
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	39.4
n	0.25	D_{xx}' (ft^2/yr)	548.22335
a_L (ft)	135	D_{yy}' (ft^2/yr)	69
a_T (ft)	17	v_x' (ft/yr)	4.061
L (ft)	1000	c_o/M (ft^{-3})	3.30E-10
W (ft)	3500		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	6		

Creek Discharge

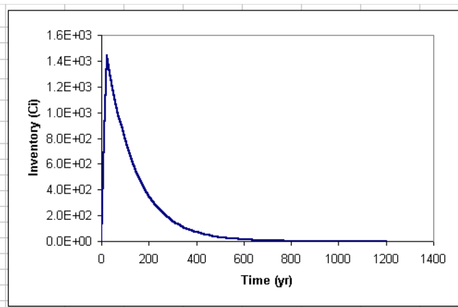
Q_c (m^3/yr)	7.80E+06

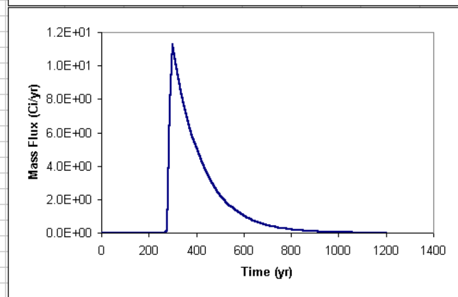
Integral Convergence Criteria

ε_1	0.01	**Local Concentration**
ε_2	0.1	**Creek Flux**

Inventory and Water Table Flux

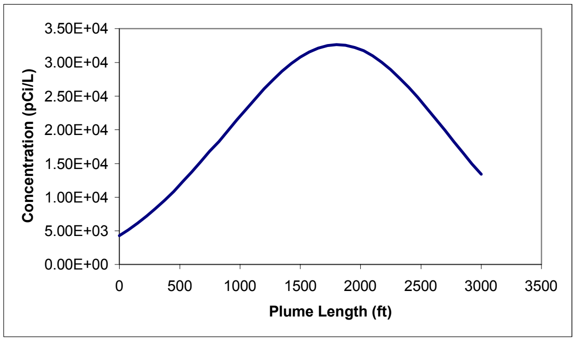
	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	1200		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	12	8.32E+02	0.00E+00	0.00E+00
2	24	1.44E+03	0.00E+00	0.00E+00
3	36	1.31E+03	0.00E+00	0.00E+00
4	48	1.19E+03	0.00E+00	0.00E+00
5	60	1.08E+03	0.00E+00	0.00E+00
6	72	9.84E+02	0.00E+00	0.00E+00
7	84	8.94E+02	0.00E+00	0.00E+00
8	96	8.13E+02	0.00E+00	0.00E+00
9	108	7.39E+02	0.00E+00	0.00E+00
10	120	6.72E+02	0.00E+00	0.00E+00
11	132	6.11E+02	0.00E+00	0.00E+00
12	144	5.56E+02	0.00E+00	0.00E+00
13	156	5.05E+02	0.00E+00	0.00E+00
14	168	4.59E+02	0.00E+00	0.00E+00
15	180	4.18E+02	0.00E+00	0.00E+00
16	192	3.80E+02	0.00E+00	0.00E+00
17	204	3.45E+02	0.00E+00	0.00E+00
18	216	3.14E+02	0.00E+00	0.00E+00
19	228	2.85E+02	0.00E+00	0.00E+00
20	240	2.60E+02	0.00E+00	0.00E+00
21	252	2.36E+02	0.00E+00	0.00E+00
22	264	2.15E+02	0.00E+00	0.00E+00
23	276	1.95E+02	1.84E-01	1.10E+00
24	288	1.77E+02	7.66E+00	4.82E+01
25	300	1.61E+02	1.13E+01	1.62E+02
26	312	1.47E+02	1.02E+01	2.91E+02
27	324	1.33E+02	9.32E+00	4.08E+02
28	336	1.21E+02	8.47E+00	5.15E+02
29	348	1.10E+02	7.70E+00	6.12E+02
30	360	1.00E+02	7.00E+00	7.00E+02
31	372	9.11E+01	6.37E+00	7.81E+02
32	384	8.28E+01	5.79E+00	8.54E+02
33	396	7.53E+01	5.26E+00	9.20E+02
34	408	6.85E+01	4.79E+00	9.80E+02
35	420	6.22E+01	4.35E+00	1.04E+03
36	432	5.66E+01	3.96E+00	1.08E+03
37	444	5.15E+01	3.60E+00	1.13E+03
38	456	4.68E+01	3.27E+00	1.17E+03
39	468	4.25E+01	2.97E+00	1.21E+03
40	480	3.87E+01	2.70E+00	1.24E+03
41	492	3.52E+01	2.46E+00	1.27E+03
42	504	3.20E+01	2.24E+00	1.30E+03
43	516	2.91E+01	2.03E+00	1.33E+03
44	528	2.64E+01	1.85E+00	1.35E+03
45	540	2.40E+01	1.68E+00	1.37E+03
46	552	2.18E+01	1.53E+00	1.39E+03
47	564	1.99E+01	1.39E+00	1.41E+03
48	576	1.81E+01	1.26E+00	1.42E+03
49	588	1.64E+01	1.15E+00	1.44E+03
50	600	1.49E+01	1.04E+00	1.45E+03
51	612	1.36E+01	9.49E-01	1.46E+03
52	624	1.23E+01	8.63E-01	1.48E+03
53	636	1.12E+01	7.85E-01	1.49E+03
54	648	1.02E+01	7.13E-01	1.49E+03
55	660	9.28E+00	6.49E-01	1.50E+03
56	672	8.43E+00	5.90E-01	1.51E+03
57	684	7.67E+00	5.36E-01	1.52E+03
58	696	6.97E+00	4.87E-01	1.52E+03
59	708	6.34E+00	4.43E-01	1.53E+03
60	720	5.76E+00	4.03E-01	1.53E+03
61	732	5.24E+00	3.66E-01	1.54E+03
62	744	4.77E+00	3.33E-01	1.54E+03
63	756	4.33E+00	3.03E-01	1.55E+03
64	768	3.94E+00	2.75E-01	1.55E+03
65	780	3.58E+00	2.50E-01	1.55E+03
66	792	3.26E+00	2.28E-01	1.56E+03
67	804	2.96E+00	2.07E-01	1.56E+03
68	816	2.69E+00	1.88E-01	1.56E+03
69	828	2.45E+00	1.71E-01	1.56E+03
70	840	2.23E+00	1.56E-01	1.56E+03
71	852	2.02E+00	1.41E-01	1.57E+03
72	864	1.84E+00	1.29E-01	1.57E+03
73	876	1.67E+00	1.17E-01	1.57E+03
74	888	1.52E+00	1.06E-01	1.57E+03
75	900	1.38E+00	9.67E-02	1.57E+03
76	912	1.26E+00	8.79E-02	1.57E+03
77	924	1.14E+00	7.99E-02	1.57E+03
78	936	1.04E+00	7.27E-02	1.57E+03
79	948	9.45E-01	6.61E-02	1.58E+03
80	960	8.59E-01	6.01E-02	1.58E+03
81	972	7.81E-01	5.46E-02	1.58E+03
82	984	7.10E-01	4.97E-02	1.58E+03
83	996	6.46E-01	4.51E-02	1.58E+03
84	1008	5.87E-01	4.10E-02	1.58E+03
85	1020	5.34E-01	3.73E-02	1.58E+03
86	1032	4.85E-01	3.39E-02	1.58E+03
87	1044	4.41E-01	3.08E-02	1.58E+03
88	1056	4.01E-01	2.80E-02	1.58E+03
89	1068	3.65E-01	2.55E-02	1.58E+03
90	1080	3.32E-01	2.32E-02	1.58E+03
91	1092	3.02E-01	2.11E-02	1.58E+03
92	1104	2.74E-01	1.92E-02	1.58E+03
93	1116	2.49E-01	1.74E-02	1.58E+03
94	1128	2.27E-01	1.58E-02	1.58E+03
95	1140	2.06E-01	1.44E-02	1.58E+03
96	1152	1.87E-01	1.31E-02	1.58E+03
97	1164	1.70E-01	1.19E-02	1.58E+03
98	1176	1.55E-01	1.08E-02	1.58E+03
99	1188	1.41E-01	9.85E-03	1.58E+03
100	1200	1.28E-01	8.95E-03	1.58E+03





Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	850



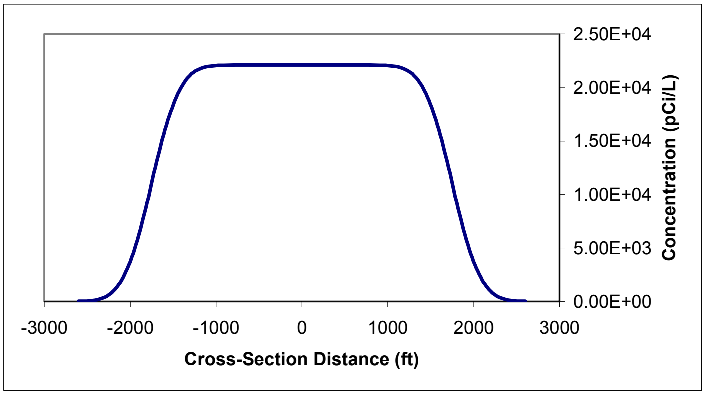
500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	4.31E+03
1	75	5.17E+03
2	150	6.13E+03
3	225	7.18E+03
4	300	8.34E+03
5	375	9.57E+03
6	450	1.09E+04
7	525	1.23E+04
8	600	1.38E+04
9	675	1.53E+04
10	750	1.68E+04
11	825	1.83E+04
12	900	1.99E+04
13	975	2.15E+04
14	1050	2.30E+04
15	1125	2.46E+04
16	1200	2.61E+04
17	1275	2.74E+04
18	1350	2.87E+04
19	1425	2.98E+04
20	1500	3.08E+04
21	1575	3.16E+04
22	1650	3.21E+04
23	1725	3.25E+04
24	1800	3.26E+04
25	1875	3.25E+04
26	1950	3.22E+04
27	2025	3.17E+04
28	2100	3.10E+04
29	2175	3.01E+04
30	2250	2.89E+04
31	2325	2.77E+04
32	2400	2.63E+04
33	2475	2.48E+04
34	2550	2.32E+04
35	2625	2.16E+04
36	2700	1.99E+04
37	2775	1.82E+04
38	2850	1.66E+04
39	2925	1.50E+04
40	3000	1.34E+04

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	850

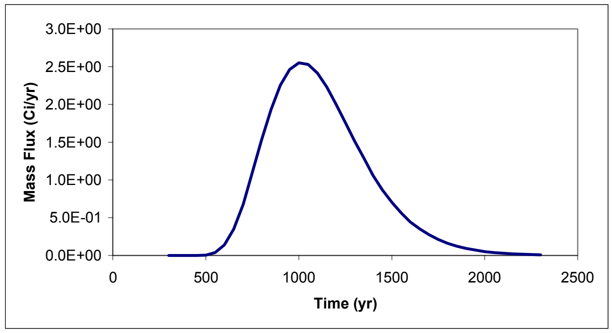
	y (ft)	C(x,y,t)
0	-2600	1.45E+01
1	-2470	6.94E+01
2	-2340	2.72E+02
3	-2210	8.70E+02
4	-2080	2.27E+03
5	-1950	4.89E+03
6	-1820	8.71E+03
7	-1690	1.31E+04
8	-1560	1.70E+04
9	-1430	1.97E+04
10	-1300	2.12E+04
11	-1170	2.18E+04
12	-1040	2.20E+04
13	-910	2.21E+04
14	-780	2.21E+04
15	-650	2.21E+04
16	-520	2.21E+04
17	-390	2.21E+04
18	-260	2.21E+04
19	-130	2.21E+04
20	0	2.21E+04
21	130	2.21E+04
22	260	2.21E+04
23	390	2.21E+04
24	520	2.21E+04
25	650	2.21E+04
26	780	2.21E+04
27	910	2.21E+04
28	1040	2.20E+04
29	1170	2.18E+04
30	1300	2.12E+04
31	1430	1.97E+04
32	1560	1.70E+04
33	1690	1.31E+04
34	1820	8.71E+03
35	1950	4.89E+03
36	2080	2.27E+03
37	2210	8.70E+02
38	2340	2.72E+02
39	2470	6.94E+01
40	2600	1.45E+01

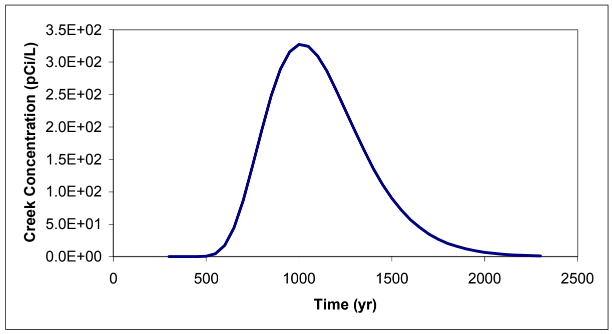


Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	300
t_{max} (yr) =	2300

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	300	0.00E+00	0.00E+00	0.00E+00
1	350	1.87E-12	4.67E-11	2.40E-10
2	400	7.71E-07	1.93E-05	9.89E-05
3	450	2.34E-04	5.90E-03	3.01E-02
4	500	5.25E-03	1.43E-01	6.73E-01
5	550	3.71E-02	1.20E+00	4.75E+00
6	600	1.38E-01	5.58E+00	1.77E+01
7	650	3.47E-01	1.77E+01	4.45E+01
8	700	6.79E-01	4.34E+01	8.70E+01
9	750	1.09E+00	8.77E+01	1.40E+02
10	800	1.53E+00	1.53E+02	1.96E+02
11	850	1.93E+00	2.40E+02	2.48E+02
12	900	2.26E+00	3.44E+02	2.89E+02
13	950	2.47E+00	4.62E+02	3.16E+02
14	1000	2.55E+00	5.88E+02	3.27E+02
15	1050	2.53E+00	7.15E+02	3.24E+02
16	1100	2.42E+00	8.39E+02	3.10E+02
17	1150	2.23E+00	9.55E+02	2.86E+02
18	1200	2.00E+00	1.06E+03	2.57E+02
19	1250	1.76E+00	1.15E+03	2.26E+02
20	1300	1.52E+00	1.24E+03	1.94E+02
21	1350	1.28E+00	1.31E+03	1.65E+02
22	1400	1.06E+00	1.37E+03	1.36E+02
23	1450	8.68E-01	1.41E+03	1.11E+02
24	1500	7.03E-01	1.45E+03	9.01E+01
25	1550	5.62E-01	1.48E+03	7.21E+01
26	1600	4.45E-01	1.51E+03	5.71E+01
27	1650	3.50E-01	1.53E+03	4.48E+01
28	1700	2.72E-01	1.55E+03	3.49E+01
29	1750	2.10E-01	1.56E+03	2.70E+01
30	1800	1.61E-01	1.57E+03	2.07E+01
31	1850	1.23E-01	1.57E+03	1.58E+01
32	1900	9.34E-02	1.58E+03	1.20E+01
33	1950	7.05E-02	1.58E+03	9.03E+00
34	2000	5.24E-02	1.59E+03	6.72E+00
35	2050	3.92E-02	1.59E+03	5.03E+00
36	2100	2.92E-02	1.59E+03	3.74E+00
37	2150	2.17E-02	1.59E+03	2.78E+00
38	2200	1.60E-02	1.59E+03	2.05E+00
39	2250	1.18E-02	1.59E+03	1.51E+00
40	2300	8.67E-03	1.59E+03	1.11E+00





Hg

Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	1.10E+04	λ_D (yr^{-1})	0.0000
Δt_R (yr)	5	I_m (Ci/yr)	628
Δt_O (yr)	20		
$T_{1/2}$ (yr)	1.00E+10		

Summary

Total Flux to Water Table (Ci) =	**1.10E+04**
Total Flux to Creek (Ci) =	**1.10E+04**
Maximum Flux to Water Table (Ci/yr) =	**4.78E+01**
Maximum Flux to Creek (Ci/yr) =	**1.07E+01**
Maximum Creek Concentration (pCi/L) =	**1.37E+03**

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.0048077
f_L	1.00	I_{max} (Ci)	10545
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^w (L/kg)	10		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	453.6
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	65
n	0.25	D_{xx}' (ft^2/yr)	332.30769
a_L (ft)	135	D_{yy}' (ft^2/yr)	42
a_T (ft)	17	v_x' (ft/yr)	2.462
L (ft)	1000	c_o/M (ft^{-3})	2.00E-10
W (ft)	3500		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	10		

Creek Discharge

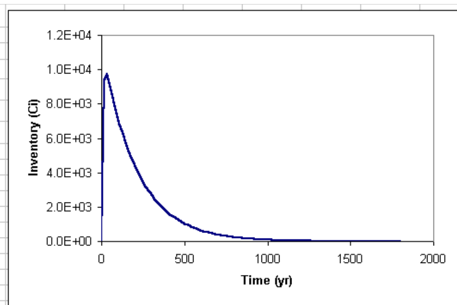
Q_c (m^3/yr)	7.80E+06

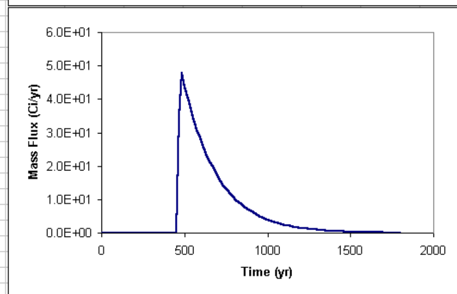
Integral Convergence Criteria

ε_1	0.01	**Local Concentration**
ε_2	0.1	**Creek Flux**

Inventory and Water Table Flux

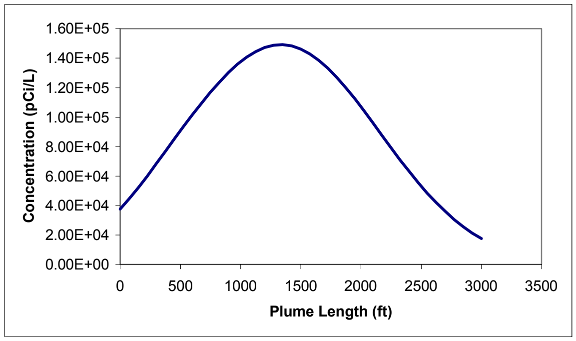
	Inventory (Ci)		Water Table Flux (Ci/yr)	
	t_{min} (yr)	0		
	t_{max} (yr)	1800		
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	18	9.38E+03	0.00E+00	0.00E+00
2	36	9.76E+03	0.00E+00	0.00E+00
3	54	8.95E+03	0.00E+00	0.00E+00
4	72	8.21E+03	0.00E+00	0.00E+00
5	90	7.53E+03	0.00E+00	0.00E+00
6	108	6.91E+03	0.00E+00	0.00E+00
7	126	6.33E+03	0.00E+00	0.00E+00
8	144	5.81E+03	0.00E+00	0.00E+00
9	162	5.33E+03	0.00E+00	0.00E+00
10	180	4.89E+03	0.00E+00	0.00E+00
11	198	4.48E+03	0.00E+00	0.00E+00
12	216	4.11E+03	0.00E+00	0.00E+00
13	234	3.77E+03	0.00E+00	0.00E+00
14	252	3.46E+03	0.00E+00	0.00E+00
15	270	3.17E+03	0.00E+00	0.00E+00
16	288	2.91E+03	0.00E+00	0.00E+00
17	306	2.67E+03	0.00E+00	0.00E+00
18	324	2.45E+03	0.00E+00	0.00E+00
19	342	2.24E+03	0.00E+00	0.00E+00
20	360	2.06E+03	0.00E+00	0.00E+00
21	378	1.89E+03	0.00E+00	0.00E+00
22	396	1.73E+03	0.00E+00	0.00E+00
23	414	1.59E+03	0.00E+00	0.00E+00
24	432	1.45E+03	0.00E+00	0.00E+00
25	450	1.33E+03	0.00E+00	0.00E+00
26	468	1.22E+03	3.49E+01	3.14E+02
27	486	1.12E+03	4.78E+01	1.06E+03
28	504	1.03E+03	4.38E+01	1.88E+03
29	522	9.44E+02	4.02E+01	2.64E+03
30	540	8.66E+02	3.68E+01	3.33E+03
31	558	7.94E+02	3.38E+01	3.97E+03
32	576	7.28E+02	3.10E+01	4.55E+03
33	594	6.68E+02	2.84E+01	5.08E+03
34	612	6.12E+02	2.61E+01	5.58E+03
35	630	5.62E+02	2.39E+01	6.03E+03
36	648	5.15E+02	2.19E+01	6.44E+03
37	666	4.72E+02	2.01E+01	6.82E+03
38	684	4.33E+02	1.84E+01	7.16E+03
39	702	3.97E+02	1.69E+01	7.48E+03
40	720	3.64E+02	1.55E+01	7.77E+03
41	738	3.34E+02	1.42E+01	8.04E+03
42	756	3.06E+02	1.30E+01	8.29E+03
43	774	2.81E+02	1.20E+01	8.51E+03
44	792	2.58E+02	1.10E+01	8.72E+03
45	810	2.36E+02	1.01E+01	8.91E+03
46	828	2.17E+02	9.23E+00	9.08E+03
47	846	1.99E+02	8.46E+00	9.24E+03
48	864	1.82E+02	7.76E+00	9.38E+03
49	882	1.67E+02	7.12E+00	9.52E+03
50	900	1.53E+02	6.53E+00	9.64E+03
51	918	1.41E+02	5.99E+00	9.75E+03
52	936	1.29E+02	5.49E+00	9.86E+03
53	954	1.18E+02	5.03E+00	9.95E+03
54	972	1.08E+02	4.62E+00	1.00E+04
55	990	9.95E+01	4.23E+00	1.01E+04
56	1008	9.12E+01	3.88E+00	1.02E+04
57	1026	8.37E+01	3.56E+00	1.03E+04
58	1044	7.67E+01	3.27E+00	1.03E+04
59	1062	7.04E+01	3.00E+00	1.04E+04
60	1080	6.45E+01	2.75E+00	1.04E+04
61	1098	5.92E+01	2.52E+00	1.05E+04
62	1116	5.43E+01	2.31E+00	1.05E+04
63	1134	4.98E+01	2.12E+00	1.06E+04
64	1152	4.57E+01	1.94E+00	1.06E+04
65	1170	4.19E+01	1.78E+00	1.06E+04
66	1188	3.84E+01	1.63E+00	1.07E+04
67	1206	3.52E+01	1.50E+00	1.07E+04
68	1224	3.23E+01	1.37E+00	1.07E+04
69	1242	2.96E+01	1.26E+00	1.07E+04
70	1260	2.72E+01	1.16E+00	1.08E+04
71	1278	2.49E+01	1.06E+00	1.08E+04
72	1296	2.28E+01	9.72E-01	1.08E+04
73	1314	2.10E+01	8.92E-01	1.08E+04
74	1332	1.92E+01	8.18E-01	1.08E+04
75	1350	1.76E+01	7.50E-01	1.08E+04
76	1368	1.62E+01	6.88E-01	1.09E+04
77	1386	1.48E+01	6.31E-01	1.09E+04
78	1404	1.36E+01	5.79E-01	1.09E+04
79	1422	1.25E+01	5.31E-01	1.09E+04
80	1440	1.14E+01	4.87E-01	1.09E+04
81	1458	1.05E+01	4.46E-01	1.09E+04
82	1476	9.62E+00	4.09E-01	1.09E+04
83	1494	8.82E+00	3.75E-01	1.09E+04
84	1512	8.09E+00	3.44E-01	1.09E+04
85	1530	7.42E+00	3.16E-01	1.09E+04
86	1548	6.80E+00	2.90E-01	1.09E+04
87	1566	6.24E+00	2.66E-01	1.09E+04
88	1584	5.72E+00	2.44E-01	1.09E+04
89	1602	5.25E+00	2.23E-01	1.10E+04
90	1620	4.81E+00	2.05E-01	1.10E+04
91	1638	4.41E+00	1.88E-01	1.10E+04
92	1656	4.05E+00	1.72E-01	1.10E+04
93	1674	3.71E+00	1.58E-01	1.10E+04
94	1692	3.40E+00	1.45E-01	1.10E+04
95	1710	3.12E+00	1.33E-01	1.10E+04
96	1728	2.86E+00	1.22E-01	1.10E+04
97	1746	2.63E+00	1.12E-01	1.10E+04
98	1764	2.41E+00	1.02E-01	1.10E+04
99	1782	2.21E+00	9.40E-02	1.10E+04
100	1800	2.03E+00	8.62E-02	1.10E+04





Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	1200



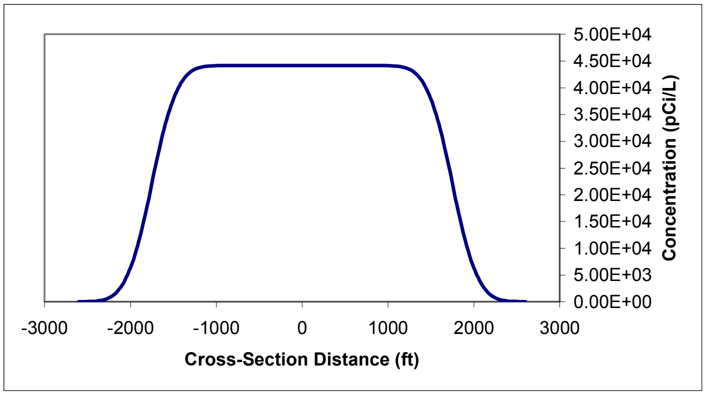
500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	3.78E+04
1	75	4.47E+04
2	150	5.21E+04
3	225	6.01E+04
4	300	6.84E+04
5	375	7.69E+04
6	450	8.54E+04
7	525	9.37E+04
8	600	1.02E+05
9	675	1.09E+05
10	750	1.17E+05
11	825	1.24E+05
12	900	1.30E+05
13	975	1.36E+05
14	1050	1.41E+05
15	1125	1.45E+05
16	1200	1.47E+05
17	1275	1.49E+05
18	1350	1.49E+05
19	1425	1.48E+05
20	1500	1.46E+05
21	1575	1.43E+05
22	1650	1.39E+05
23	1725	1.33E+05
24	1800	1.27E+05
25	1875	1.20E+05
26	1950	1.12E+05
27	2025	1.04E+05
28	2100	9.61E+04
29	2175	8.77E+04
30	2250	7.94E+04
31	2325	7.12E+04
32	2400	6.32E+04
33	2475	5.57E+04
34	2550	4.86E+04
35	2625	4.20E+04
36	2700	3.60E+04
37	2775	3.06E+04
38	2850	2.57E+04
39	2925	2.14E+04
40	3000	1.77E+04

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	1200

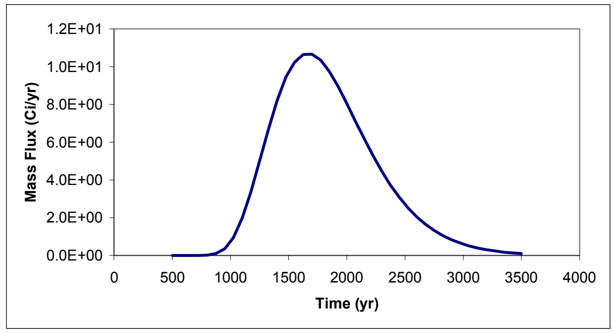
	y (ft)	C(x,y,t)
0	-2600	7.32E+00
1	-2470	5.04E+01
2	-2340	2.68E+02
3	-2210	1.10E+03
4	-2080	3.49E+03
5	-1950	8.64E+03
6	-1820	1.69E+04
7	-1690	2.66E+04
8	-1560	3.50E+04
9	-1430	4.04E+04
10	-1300	4.30E+04
11	-1170	4.39E+04
12	-1040	4.41E+04
13	-910	4.42E+04
14	-780	4.42E+04
15	-650	4.42E+04
16	-520	4.42E+04
17	-390	4.42E+04
18	-260	4.42E+04
19	-130	4.42E+04
20	0	4.42E+04
21	130	4.42E+04
22	260	4.42E+04
23	390	4.42E+04
24	520	4.42E+04
25	650	4.42E+04
26	780	4.42E+04
27	910	4.42E+04
28	1040	4.41E+04
29	1170	4.39E+04
30	1300	4.30E+04
31	1430	4.04E+04
32	1560	3.50E+04
33	1690	2.66E+04
34	1820	1.69E+04
35	1950	8.64E+03
36	2080	3.49E+03
37	2210	1.10E+03
38	2340	2.68E+02
39	2470	5.04E+01
40	2600	7.32E+00

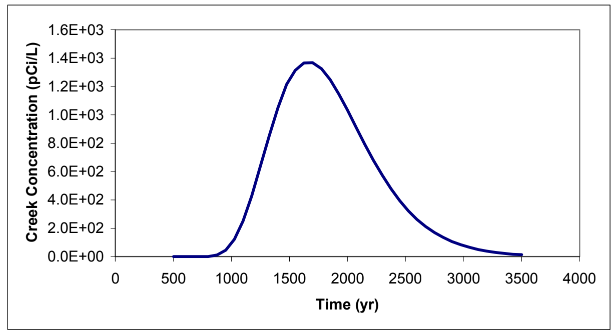


Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	500
t_{max} (yr) =	3500

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	500	0.00E+00	0.00E+00	0.00E+00
1	575	7.42E-12	2.78E-10	9.51E-10
2	650	1.86E-06	6.98E-05	2.39E-04
3	725	5.09E-04	1.92E-02	6.52E-02
4	800	1.22E-02	4.94E-01	1.56E+00
5	875	9.17E-02	4.39E+00	1.18E+01
6	950	3.58E-01	2.13E+01	4.59E+01
7	1025	9.54E-01	7.05E+01	1.22E+02
8	1100	1.96E+00	1.80E+02	2.51E+02
9	1175	3.34E+00	3.78E+02	4.28E+02
10	1250	4.97E+00	6.90E+02	6.38E+02
11	1325	6.66E+00	1.13E+03	8.54E+02
12	1400	8.20E+00	1.68E+03	1.05E+03
13	1475	9.47E+00	2.35E+03	1.21E+03
14	1550	1.02E+01	3.09E+03	1.31E+03
15	1625	1.07E+01	3.87E+03	1.37E+03
16	1700	1.07E+01	4.67E+03	1.37E+03
17	1775	1.03E+01	5.46E+03	1.33E+03
18	1850	9.73E+00	6.21E+03	1.25E+03
19	1925	8.95E+00	6.91E+03	1.15E+03
20	2000	8.06E+00	7.55E+03	1.03E+03
21	2075	7.11E+00	8.12E+03	9.12E+02
22	2150	6.18E+00	8.61E+03	7.92E+02
23	2225	5.29E+00	9.04E+03	6.78E+02
24	2300	4.47E+00	9.41E+03	5.74E+02
25	2375	3.74E+00	9.72E+03	4.79E+02
26	2450	3.09E+00	9.98E+03	3.96E+02
27	2525	2.53E+00	1.02E+04	3.25E+02
28	2600	2.06E+00	1.04E+04	2.64E+02
29	2675	1.66E+00	1.05E+04	2.13E+02
30	2750	1.33E+00	1.06E+04	1.70E+02
31	2825	1.05E+00	1.07E+04	1.35E+02
32	2900	8.33E-01	1.08E+04	1.07E+02
33	2975	6.55E-01	1.08E+04	8.39E+01
34	3050	5.09E-01	1.09E+04	6.53E+01
35	3125	3.97E-01	1.09E+04	5.08E+01
36	3200	3.08E-01	1.09E+04	3.94E+01
37	3275	2.37E-01	1.09E+04	3.04E+01
38	3350	1.80E-01	1.10E+04	2.31E+01
39	3425	1.38E-01	1.10E+04	1.77E+01
40	3500	1.05E-01	1.10E+04	1.35E+01





Pb

Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	**5.00E+04**	λ_D (yr^{-1})	0.0000
Δt_R (yr)	**5**	I_m (Ci/yr)	2857
Δt_O (yr)	**20**		
$T_{1/2}$ (yr)	**1.00E+10**		

Summary

Total Flux to Water Table (Ci) =	**4.99E+04**
Total Flux to Creek (Ci) =	**4.99E+04**
Maximum Flux to Water Table (Ci/yr) =	**2.32E+01**
Maximum Flux to Creek (Ci/yr) =	**4.93E+00**
Maximum Creek Concentration (pCi/L) =	**6.32E+02**

Leaching

q_f (ft/yr)	**1.25**	λ_L (yr^{-1})	0.0004875
f_L	**1.00**	I_{max} (Ci)	49786
θ_{waste}	**0.25**		
ρ_{waste} (kg/L)	**1.6**		
K_d^w (L/kg)	**100**		
L_{waste} (ft)	**16**		

Vadose Zone

L_{vz} (ft)	**35**	Δt_{vz} (yr)	4485.6
θ_{vz}	**0.2**		

Aquifer Parameters

q_x (ft/yr)	**40**	R	641
n	**0.25**	D_{xx}' (ft^2/yr)	33.697348
a_L (ft)	**135**	D_{yy}' (ft^2/yr)	4
a_T (ft)	**17**	v_x' (ft/yr)	0.250
L (ft)	**1000**	c_o/M (ft^{-3})	2.03E-11
W (ft)	**3500**		
H (ft)	**22**		
ρ_b (kg/L)	**1.6**		
K_d (L/kg)	**100**		

Creek Discharge

Q_c (m^3/yr)	**7.80E+06**

Integral Convergence Criteria

ε_1	**0.01**	**Local Concentration**
ε_2	**0.1**	**Creek Flux**

Inventory and Water Table Flux

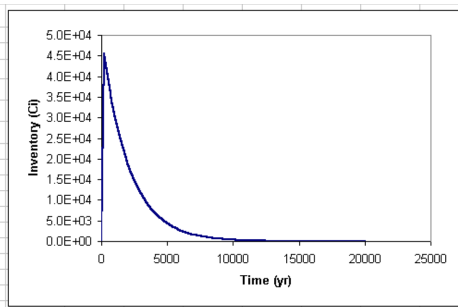
Inventory (Ci)

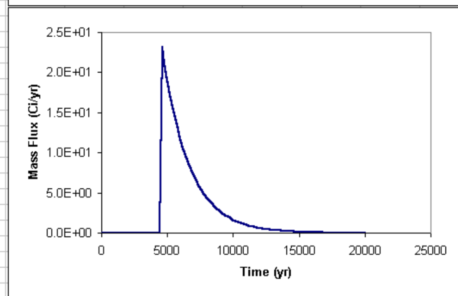
t_{min} (yr): 0

t_{max} (yr): 20000

Water Table Flux (Ci/yr)

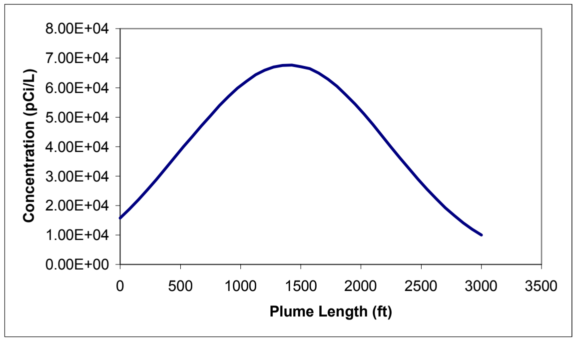
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	200	4.56E+04	0.00E+00	0.00E+00
2	400	4.14E+04	0.00E+00	0.00E+00
3	600	3.75E+04	0.00E+00	0.00E+00
4	800	3.40E+04	0.00E+00	0.00E+00
5	1000	3.09E+04	0.00E+00	0.00E+00
6	1200	2.80E+04	0.00E+00	0.00E+00
7	1400	2.54E+04	0.00E+00	0.00E+00
8	1600	2.30E+04	0.00E+00	0.00E+00
9	1800	2.09E+04	0.00E+00	0.00E+00
10	2000	1.90E+04	0.00E+00	0.00E+00
11	2200	1.72E+04	0.00E+00	0.00E+00
12	2400	1.56E+04	0.00E+00	0.00E+00
13	2600	1.42E+04	0.00E+00	0.00E+00
14	2800	1.28E+04	0.00E+00	0.00E+00
15	3000	1.16E+04	0.00E+00	0.00E+00
16	3200	1.06E+04	0.00E+00	0.00E+00
17	3400	9.58E+03	0.00E+00	0.00E+00
18	3600	8.69E+03	0.00E+00	0.00E+00
19	3800	7.88E+03	0.00E+00	0.00E+00
20	4000	7.15E+03	0.00E+00	0.00E+00
21	4200	6.49E+03	0.00E+00	0.00E+00
22	4400	5.88E+03	0.00E+00	0.00E+00
23	4600	5.34E+03	2.32E+01	2.32E+03
24	4800	4.84E+03	2.10E+01	6.74E+03
25	5000	4.39E+03	1.91E+01	1.07E+04
26	5200	3.98E+03	1.73E+01	1.44E+04
27	5400	3.61E+03	1.57E+01	1.77E+04
28	5600	3.28E+03	1.42E+01	2.07E+04
29	5800	2.97E+03	1.29E+01	2.34E+04
30	6000	2.70E+03	1.17E+01	2.59E+04
31	6200	2.45E+03	1.06E+01	2.81E+04
32	6400	2.22E+03	9.64E+00	3.01E+04
33	6600	2.01E+03	8.74E+00	3.20E+04
34	6800	1.83E+03	7.93E+00	3.36E+04
35	7000	1.66E+03	7.19E+00	3.51E+04
36	7200	1.50E+03	6.53E+00	3.65E+04
37	7400	1.36E+03	5.92E+00	3.78E+04
38	7600	1.24E+03	5.37E+00	3.89E+04
39	7800	1.12E+03	4.87E+00	3.99E+04
40	8000	1.02E+03	4.42E+00	4.08E+04
41	8200	9.23E+02	4.01E+00	4.17E+04
42	8400	8.37E+02	3.64E+00	4.24E+04
43	8600	7.59E+02	3.30E+00	4.31E+04
44	8800	6.89E+02	2.99E+00	4.38E+04
45	9000	6.25E+02	2.71E+00	4.43E+04
46	9200	5.67E+02	2.46E+00	4.48E+04
47	9400	5.14E+02	2.23E+00	4.53E+04
48	9600	4.66E+02	2.03E+00	4.57E+04
49	9800	4.23E+02	1.84E+00	4.61E+04
50	10000	3.84E+02	1.67E+00	4.65E+04
51	10200	3.48E+02	1.51E+00	4.68E+04
52	10400	3.16E+02	1.37E+00	4.71E+04
53	10600	2.86E+02	1.24E+00	4.73E+04
54	10800	2.60E+02	1.13E+00	4.76E+04
55	11000	2.36E+02	1.02E+00	4.78E+04
56	11200	2.14E+02	9.28E-01	4.80E+04
57	11400	1.94E+02	8.42E-01	4.82E+04
58	11600	1.76E+02	7.64E-01	4.83E+04
59	11800	1.60E+02	6.93E-01	4.85E+04
60	12000	1.45E+02	6.29E-01	4.86E+04
61	12200	1.31E+02	5.70E-01	4.87E+04
62	12400	1.19E+02	5.17E-01	4.88E+04
63	12600	1.08E+02	4.69E-01	4.89E+04
64	12800	9.80E+01	4.26E-01	4.90E+04
65	13000	8.89E+01	3.86E-01	4.91E+04
66	13200	8.06E+01	3.50E-01	4.92E+04
67	13400	7.31E+01	3.18E-01	4.93E+04
68	13600	6.64E+01	2.88E-01	4.93E+04
69	13800	6.02E+01	2.61E-01	4.94E+04
70	14000	5.46E+01	2.37E-01	4.94E+04
71	14200	4.95E+01	2.15E-01	4.95E+04
72	14400	4.49E+01	1.95E-01	4.95E+04
73	14600	4.07E+01	1.77E-01	4.95E+04
74	14800	3.70E+01	1.61E-01	4.96E+04
75	15000	3.35E+01	1.46E-01	4.96E+04
76	15200	3.04E+01	1.32E-01	4.96E+04
77	15400	2.76E+01	1.20E-01	4.97E+04
78	15600	2.50E+01	1.09E-01	4.97E+04
79	15800	2.27E+01	9.86E-02	4.97E+04
80	16000	2.06E+01	8.94E-02	4.97E+04
81	16200	1.87E+01	8.11E-02	4.97E+04
82	16400	1.69E+01	7.36E-02	4.98E+04
83	16600	1.54E+01	6.67E-02	4.98E+04
84	16800	1.39E+01	6.05E-02	4.98E+04
85	17000	1.26E+01	5.49E-02	4.98E+04
86	17200	1.15E+01	4.98E-02	4.98E+04
87	17400	1.04E+01	4.52E-02	4.98E+04
88	17600	9.44E+00	4.10E-02	4.98E+04
89	17800	8.56E+00	3.72E-02	4.98E+04
90	18000	7.77E+00	3.37E-02	4.98E+04
91	18200	7.05E+00	3.06E-02	4.98E+04
92	18400	6.39E+00	2.78E-02	4.98E+04
93	18600	5.80E+00	2.52E-02	4.99E+04
94	18800	5.26E+00	2.28E-02	4.99E+04
95	19000	4.77E+00	2.07E-02	4.99E+04
96	19200	4.33E+00	1.88E-02	4.99E+04
97	19400	3.92E+00	1.70E-02	4.99E+04
98	19600	3.56E+00	1.55E-02	4.99E+04
99	19800	3.23E+00	1.40E-02	4.99E+04
100	20000	2.93E+00	1.27E-02	4.99E+04





Plume Profile

x_{min} (ft) =	0
x_{max} (ft) =	3000
y (ft) =	0
t (yr) =	12000



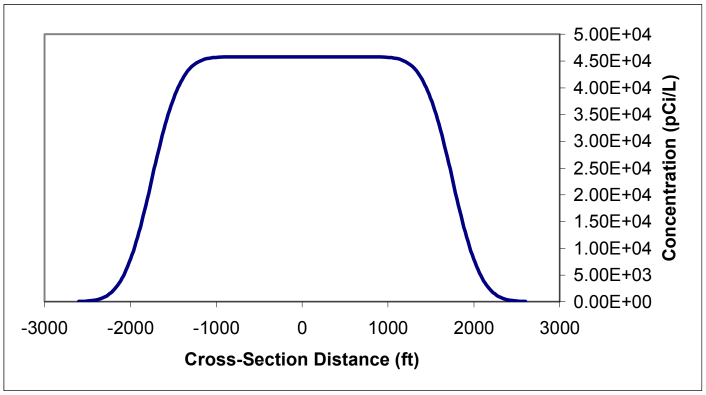
500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	1.58E+04
1	75	1.87E+04
2	150	2.19E+04
3	225	2.53E+04
4	300	2.89E+04
5	375	3.26E+04
6	450	3.63E+04
7	525	3.99E+04
8	600	4.35E+04
9	675	4.70E+04
10	750	5.04E+04
11	825	5.40E+04
12	900	5.70E+04
13	975	5.98E+04
14	1050	6.23E+04
15	1125	6.43E+04
16	1200	6.59E+04
17	1275	6.70E+04
18	1350	6.76E+04
19	1425	6.76E+04
20	1500	6.71E+04
21	1575	6.64E+04
22	1650	6.49E+04
23	1725	6.29E+04
24	1800	6.04E+04
25	1875	5.76E+04
26	1950	5.44E+04
27	2025	5.10E+04
28	2100	4.74E+04
29	2175	4.37E+04
30	2250	3.99E+04
31	2325	3.61E+04
32	2400	3.25E+04
33	2475	2.89E+04
34	2550	2.55E+04
35	2625	2.23E+04
36	2700	1.93E+04
37	2775	1.66E+04
38	2850	1.41E+04
39	2925	1.19E+04
40	3000	9.97E+03

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	14000

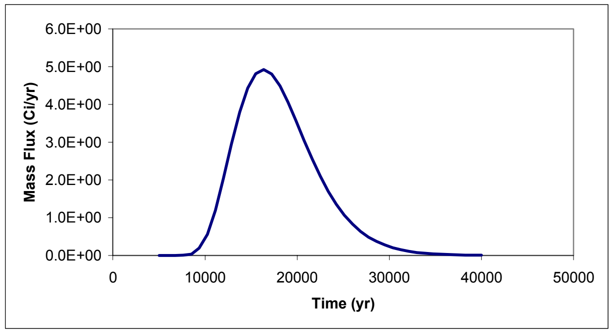
	y (ft)	C(x,y,t)
0	-2600	3.58E+01
1	-2470	1.64E+02
2	-2340	6.19E+02
3	-2210	1.92E+03
4	-2080	4.88E+03
5	-1950	1.03E+04
6	-1820	1.81E+04
7	-1690	2.70E+04
8	-1560	3.50E+04
9	-1430	4.06E+04
10	-1300	4.37E+04
11	-1170	4.51E+04
12	-1040	4.56E+04
13	-910	4.58E+04
14	-780	4.58E+04
15	-650	4.58E+04
16	-520	4.58E+04
17	-390	4.58E+04
18	-260	4.58E+04
19	-130	4.58E+04
20	0	4.58E+04
21	130	4.58E+04
22	260	4.58E+04
23	390	4.58E+04
24	520	4.58E+04
25	650	4.58E+04
26	780	4.58E+04
27	910	4.58E+04
28	1040	4.56E+04
29	1170	4.51E+04
30	1300	4.37E+04
31	1430	4.06E+04
32	1560	3.50E+04
33	1690	2.70E+04
34	1820	1.81E+04
35	1950	1.03E+04
36	2080	4.88E+03
37	2210	1.92E+03
38	2340	6.19E+02
39	2470	1.64E+02
40	2600	3.58E+01

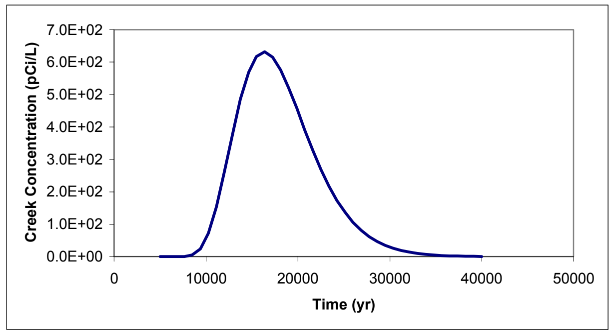


Creek Flux and Concentration

X_c (ft) =	**2600**
y_{max} (ft) =	**2600**
t_{min} (yr) =	**5000**
t_{max} (yr) =	**40000**

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	5000	0.00E+00	0.00E+00	0.00E+00
1	5875	1.33E-09	5.81E-07	1.70E-07
2	6750	3.17E-05	1.39E-02	4.07E-03
3	7625	2.93E-03	1.31E+00	3.75E-01
4	8500	3.80E-02	1.92E+01	4.87E+00
5	9375	1.90E-01	1.19E+02	2.43E+01
6	10250	5.62E-01	4.48E+02	7.21E+01
7	11125	1.20E+00	1.22E+03	1.54E+02
8	12000	2.04E+00	2.63E+03	2.62E+02
9	12875	2.96E+00	4.82E+03	3.79E+02
10	13750	3.79E+00	7.77E+03	4.86E+02
11	14625	4.44E+00	1.14E+04	5.69E+02
12	15500	4.82E+00	1.54E+04	6.18E+02
13	16375	4.93E+00	1.97E+04	6.32E+02
14	17250	4.80E+00	2.39E+04	6.16E+02
15	18125	4.49E+00	2.80E+04	5.76E+02
16	19000	4.06E+00	3.17E+04	5.20E+02
17	19875	3.56E+00	3.51E+04	4.57E+02
18	20750	3.05E+00	3.80E+04	3.91E+02
19	21625	2.56E+00	4.04E+04	3.28E+02
20	22500	2.10E+00	4.25E+04	2.69E+02
21	23375	1.70E+00	4.41E+04	2.18E+02
22	24250	1.35E+00	4.55E+04	1.74E+02
23	25125	1.06E+00	4.65E+04	1.36E+02
24	26000	8.28E-01	4.74E+04	1.06E+02
25	26875	6.37E-01	4.80E+04	8.16E+01
26	27750	4.85E-01	4.85E+04	6.22E+01
27	28625	3.67E-01	4.89E+04	4.70E+01
28	29500	2.75E-01	4.91E+04	3.53E+01
29	30375	2.05E-01	4.93E+04	2.62E+01
30	31250	1.51E-01	4.95E+04	1.94E+01
31	32125	1.10E-01	4.96E+04	1.41E+01
32	33000	8.08E-02	4.97E+04	1.04E+01
33	33875	5.89E-02	4.98E+04	7.55E+00
34	34750	4.27E-02	4.98E+04	5.48E+00
35	35625	3.08E-02	4.98E+04	3.95E+00
36	36500	2.22E-02	4.99E+04	2.84E+00
37	37375	1.59E-02	4.99E+04	2.04E+00
38	38250	1.14E-02	4.99E+04	1.46E+00
39	39125	8.10E-03	4.99E+04	1.04E+00
40	40000	5.75E-03	4.99E+04	7.38E-01





VOCs

Groundwater Transport - SRS ORWBG

Delivered Inventory and Nulide Decay

I_o (Ci)	2.82E+04	λ_D (yr^{-1})	0.0069
Δt_R (yr)	5	I_m (Ci/yr)	1611
Δt_O (yr)	20		
$T_{1/2}$ (yr)	1.00E+02		

Summary

Total Flux to Water Table (Ci) =	2.54E+04
Total Flux to Creek (Ci) =	2.07E+04
Maximum Flux to Water Table (Ci/yr) =	1.40E+03
Maximum Flux to Creek (Ci/yr) =	7.24E+02
Maximum Creek Concentration (pCi/L) =	9.28E+04

Leaching

q_f (ft/yr)	1.25	λ_L (yr^{-1})	0.1905488
f_L	1.00	I_{max} (Ci)	7892
θ_{waste}	0.25		
ρ_{waste} (kg/L)	1.6		
K_d^w (L/kg)	0.1		
L_{waste} (ft)	16		

Vadose Zone

L_{vz} (ft)	35	Δt_{vz} (yr)	10.08
θ_{vz}	0.2		

Aquifer Parameters

q_x (ft/yr)	40	R	1.64
n	0.25	D_{xx}' (ft^2/yr)	13170.732
a_L (ft)	135	D_{yy}' (ft^2/yr)	1659
a_T (ft)	17	v_x' (ft/yr)	97.561
L (ft)	1000	c_o/M (ft^{-3})	7.92E-09
W (ft)	3500		
H (ft)	22		
ρ_b (kg/L)	1.6		
K_d (L/kg)	0.1		

Creek Discharge

Q_c (m^3/yr)	7.80E+06

Integral Convergence Criteria

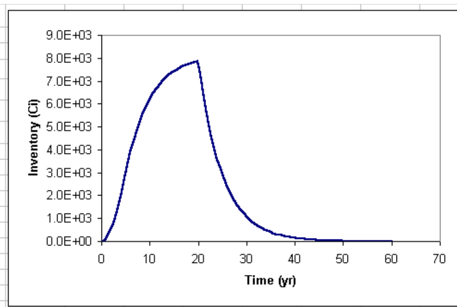
ε_1	0.001	Local Concentration
ε_2	0.01	Creek Flux

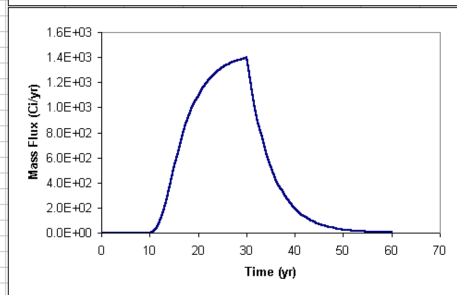
Inventory and Water Table Flux

Inventory (Ci)
t_{min} (yr) 0
t_{max} (yr) 60

Water Table Flux (Ci/yr)

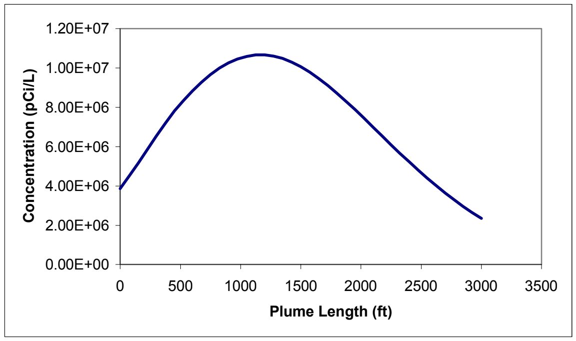
	t (yr)	I (Ci)	$m'_{wt}(t)$	$\Sigma m'_{wt}(t)$
0	0	0.00E+00	0.00E+00	0
1	0.6	5.58E+01	0.00E+00	0.00E+00
2	1.2	2.15E+02	0.00E+00	0.00E+00
3	1.8	4.65E+02	0.00E+00	0.00E+00
4	2.4	7.97E+02	0.00E+00	0.00E+00
5	3	1.20E+03	0.00E+00	0.00E+00
6	3.6	1.67E+03	0.00E+00	0.00E+00
7	4.2	2.20E+03	0.00E+00	0.00E+00
8	4.8	2.77E+03	0.00E+00	0.00E+00
9	5.4	3.37E+03	0.00E+00	0.00E+00
10	6	3.90E+03	0.00E+00	0.00E+00
11	6.6	4.38E+03	0.00E+00	0.00E+00
12	7.2	4.80E+03	0.00E+00	0.00E+00
13	7.8	5.18E+03	0.00E+00	0.00E+00
14	8.4	5.51E+03	0.00E+00	0.00E+00
15	9	5.81E+03	0.00E+00	0.00E+00
16	9.6	6.07E+03	0.00E+00	0.00E+00
17	10.2	6.30E+03	4.09E-01	1.23E-01
18	10.8	6.51E+03	1.42E+01	4.49E+00
19	11.4	6.69E+03	4.58E+01	2.25E+01
20	12	6.86E+03	9.34E+01	6.43E+01
21	12.6	7.00E+03	1.55E+02	1.39E+02
22	13.2	7.13E+03	2.29E+02	2.54E+02
23	13.8	7.25E+03	3.15E+02	4.17E+02
24	14.4	7.35E+03	4.10E+02	6.35E+02
25	15	7.44E+03	5.14E+02	9.12E+02
26	15.6	7.52E+03	6.18E+02	1.25E+03
27	16.2	7.59E+03	7.11E+02	1.65E+03
28	16.8	7.66E+03	7.94E+02	2.10E+03
29	17.4	7.71E+03	8.67E+02	2.60E+03
30	18	7.76E+03	9.32E+02	3.14E+03
31	18.6	7.81E+03	9.90E+02	3.72E+03
32	19.2	7.85E+03	1.04E+03	4.33E+03
33	19.8	7.88E+03	1.09E+03	4.97E+03
34	20.4	7.29E+03	1.13E+03	5.63E+03
35	21	6.48E+03	1.16E+03	6.32E+03
36	21.6	5.75E+03	1.20E+03	7.03E+03
37	22.2	5.11E+03	1.22E+03	7.75E+03
38	22.8	4.54E+03	1.25E+03	8.49E+03
39	23.4	4.03E+03	1.27E+03	9.25E+03
40	24	3.58E+03	1.29E+03	1.00E+04
41	24.6	3.18E+03	1.31E+03	1.08E+04
42	25.2	2.83E+03	1.33E+03	1.16E+04
43	25.8	2.51E+03	1.34E+03	1.24E+04
44	26.4	2.23E+03	1.35E+03	1.32E+04
45	27	1.98E+03	1.36E+03	1.40E+04
46	27.6	1.76E+03	1.37E+03	1.48E+04
47	28.2	1.56E+03	1.38E+03	1.57E+04
48	28.8	1.39E+03	1.39E+03	1.65E+04
49	29.4	1.23E+03	1.40E+03	1.73E+04
50	30	1.10E+03	1.40E+03	1.82E+04
51	30.6	9.73E+02	1.27E+03	1.90E+04
52	31.2	8.64E+02	1.12E+03	1.97E+04
53	31.8	7.68E+02	9.98E+02	2.03E+04
54	32.4	6.82E+02	8.87E+02	2.09E+04
55	33	6.06E+02	7.88E+02	2.14E+04
56	33.6	5.38E+02	7.00E+02	2.18E+04
57	34.2	4.78E+02	6.22E+02	2.22E+04
58	34.8	4.24E+02	5.52E+02	2.26E+04
59	35.4	3.77E+02	4.90E+02	2.29E+04
60	36	3.35E+02	4.36E+02	2.32E+04
61	36.6	2.97E+02	3.87E+02	2.34E+04
62	37.2	2.64E+02	3.44E+02	2.36E+04
63	37.8	2.35E+02	3.05E+02	2.38E+04
64	38.4	2.09E+02	2.71E+02	2.40E+04
65	39	1.85E+02	2.41E+02	2.42E+04
66	39.6	1.65E+02	2.14E+02	2.43E+04
67	40.2	1.46E+02	1.90E+02	2.44E+04
68	40.8	1.30E+02	1.69E+02	2.45E+04
69	41.4	1.15E+02	1.50E+02	2.46E+04
70	42	1.02E+02	1.33E+02	2.47E+04
71	42.6	9.10E+01	1.18E+02	2.48E+04
72	43.2	8.08E+01	1.05E+02	2.48E+04
73	43.8	7.18E+01	9.34E+01	2.49E+04
74	44.4	6.38E+01	8.29E+01	2.50E+04
75	45	5.66E+01	7.37E+01	2.50E+04
76	45.6	5.03E+01	6.54E+01	2.50E+04
77	46.2	4.47E+01	5.81E+01	2.51E+04
78	46.8	3.97E+01	5.16E+01	2.51E+04
79	47.4	3.53E+01	4.59E+01	2.51E+04
80	48	3.13E+01	4.07E+01	2.52E+04
81	48.6	2.78E+01	3.62E+01	2.52E+04
82	49.2	2.47E+01	3.21E+01	2.52E+04
83	49.8	2.19E+01	2.85E+01	2.52E+04
84	50.4	1.95E+01	2.54E+01	2.52E+04
85	51	1.73E+01	2.25E+01	2.53E+04
86	51.6	1.54E+01	2.00E+01	2.53E+04
87	52.2	1.37E+01	1.78E+01	2.53E+04
88	52.8	1.21E+01	1.58E+01	2.53E+04
89	53.4	1.08E+01	1.40E+01	2.53E+04
90	54	9.58E+00	1.25E+01	2.53E+04
91	54.6	8.51E+00	1.11E+01	2.53E+04
92	55.2	7.56E+00	9.83E+00	2.53E+04
93	55.8	6.71E+00	8.73E+00	2.53E+04
94	56.4	5.96E+00	7.75E+00	2.53E+04
95	57	5.30E+00	6.89E+00	2.53E+04
96	57.6	4.70E+00	6.12E+00	2.53E+04
97	58.2	4.18E+00	5.43E+00	2.53E+04
98	58.8	3.71E+00	4.83E+00	2.54E+04
99	59.4	3.30E+00	4.29E+00	2.54E+04
100	60	2.93E+00	3.81E+00	2.54E+04





Plume Profile

x_{min} (ft) =	**0**
x_{max} (ft) =	**3000**
y (ft) =	**0**
t (yr) =	**40**

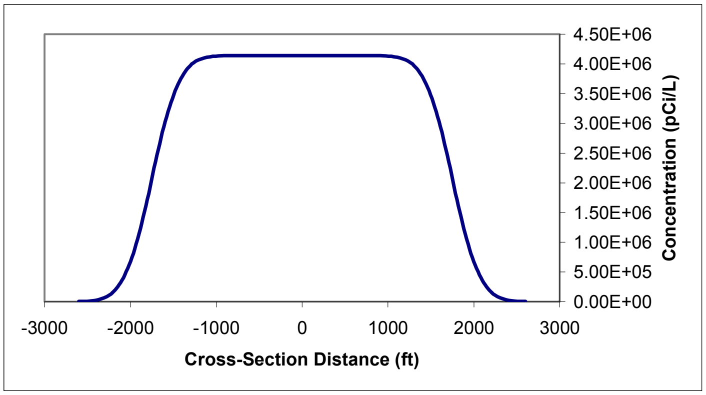


500	0
500	1.00E+08

	x (ft)	C(x;y,t)
0	0	3.87E+06
1	75	4.50E+06
2	150	5.17E+06
3	225	5.85E+06
4	300	6.53E+06
5	375	7.20E+06
6	450	7.81E+06
7	525	8.35E+06
8	600	8.83E+06
9	675	9.27E+06
10	750	9.66E+06
11	825	1.00E+07
12	900	1.03E+07
13	975	1.05E+07
14	1050	1.06E+07
15	1125	1.07E+07
16	1200	1.07E+07
17	1275	1.06E+07
18	1350	1.05E+07
19	1425	1.03E+07
20	1500	1.01E+07
21	1575	9.79E+06
22	1650	9.46E+06
23	1725	9.11E+06
24	1800	8.72E+06
25	1875	8.31E+06
26	1950	7.88E+06
27	2025	7.45E+06
28	2100	7.00E+06
29	2175	6.55E+06
30	2250	6.10E+06
31	2325	5.66E+06
32	2400	5.23E+06
33	2475	4.81E+06
34	2550	4.40E+06
35	2625	4.01E+06
36	2700	3.64E+06
37	2775	3.29E+06
38	2850	2.96E+06
39	2925	2.65E+06
40	3000	2.36E+06

Plume Cross-section

x (ft) =	2600
y_{max} (ft) =	2600
t (yr) =	40

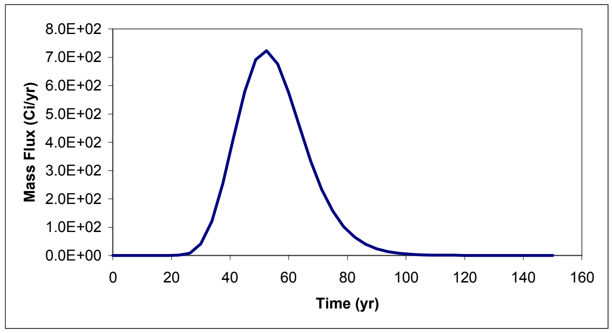


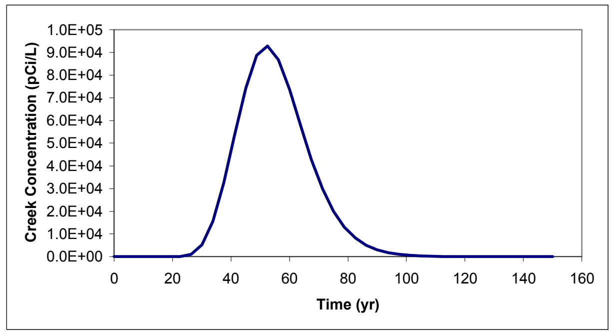
	y (ft)	C(x,y,t)
0	-2600	2.74E+03
1	-2470	1.25E+04
2	-2340	4.76E+04
3	-2210	1.52E+05
4	-2080	4.05E+05
5	-1950	8.91E+05
6	-1820	1.62E+06
7	-1690	2.46E+06
8	-1560	3.20E+06
9	-1430	3.71E+06
10	-1300	3.98E+06
11	-1170	4.09E+06
12	-1040	4.13E+06
13	-910	4.14E+06
14	-780	4.14E+06
15	-650	4.14E+06
16	-520	4.14E+06
17	-390	4.14E+06
18	-260	4.14E+06
19	-130	4.14E+06
20	0	4.14E+06
21	130	4.14E+06
22	260	4.14E+06
23	390	4.14E+06
24	520	4.14E+06
25	650	4.14E+06
26	780	4.14E+06
27	910	4.14E+06
28	1040	4.13E+06
29	1170	4.09E+06
30	1300	3.98E+06
31	1430	3.71E+06
32	1560	3.20E+06
33	1690	2.46E+06
34	1820	1.62E+06
35	1950	8.91E+05
36	2080	4.05E+05
37	2210	1.52E+05
38	2340	4.76E+04
39	2470	1.25E+04
40	2600	2.74E+03

Creek Flux and Concentration

X_c (ft) =	2600
y_{max} (ft) =	2600
t_{min} (yr) =	0
t_{max} (yr) =	150

	t (yr)	$m'_{ck}(X_c,y;t)$	$\Sigma\, m'_{ck}(X_c,y;t)$	pCi/L $C_c(t)$
0	0	0.00E+00	0.00E+00	0.00E+00
1	3.75	0.00E+00	0.00E+00	0.00E+00
2	7.5	0.00E+00	0.00E+00	0.00E+00
3	11.25	0.00E+00	0.00E+00	0.00E+00
4	15	2.42E-07	4.54E-07	3.10E-05
5	18.75	6.61E-03	1.24E-02	8.47E-01
6	22.5	6.04E-01	1.16E+00	7.75E+01
7	26.25	8.02E+00	1.73E+01	1.03E+03
8	30	4.12E+01	1.10E+02	5.28E+03
9	33.75	1.22E+02	4.15E+02	1.56E+04
10	37.5	2.53E+02	1.12E+03	3.25E+04
11	41.25	4.18E+02	2.38E+03	5.36E+04
12	45	5.80E+02	4.25E+03	7.43E+04
13	48.75	6.92E+02	6.63E+03	8.87E+04
14	52.5	7.24E+02	9.29E+03	9.28E+04
15	56.25	6.76E+02	1.19E+04	8.67E+04
16	60	5.75E+02	1.43E+04	7.37E+04
17	63.75	4.52E+02	1.62E+04	5.79E+04
18	67.5	3.34E+02	1.77E+04	4.28E+04
19	71.25	2.34E+02	1.87E+04	3.00E+04
20	75	1.57E+02	1.95E+04	2.02E+04
21	78.75	1.02E+02	1.99E+04	1.31E+04
22	82.5	6.42E+01	2.03E+04	8.23E+03
23	86.25	3.94E+01	2.04E+04	5.06E+03
24	90	2.37E+01	2.06E+04	3.04E+03
25	93.75	1.40E+01	2.06E+04	1.79E+03
26	97.5	8.12E+00	2.07E+04	1.04E+03
27	101.25	4.65E+00	2.07E+04	5.96E+02
28	105	2.63E+00	2.07E+04	3.37E+02
29	108.75	1.47E+00	2.07E+04	1.89E+02
30	112.5	8.17E-01	2.07E+04	1.05E+02
31	116.25	4.49E-01	2.07E+04	5.76E+01
32	120	2.45E-01	2.07E+04	3.14E+01
33	123.75	1.33E-01	2.07E+04	1.70E+01
34	127.5	7.15E-02	2.07E+04	9.17E+00
35	131.25	3.83E-02	2.07E+04	4.91E+00
36	135	2.04E-02	2.07E+04	2.62E+00
37	138.75	1.08E-02	2.07E+04	1.39E+00
38	142.5	5.72E-03	2.07E+04	7.33E-01
39	146.25	3.01E-03	2.07E+04	3.86E-01
40	150	1.58E-03	2.07E+04	2.02E-01



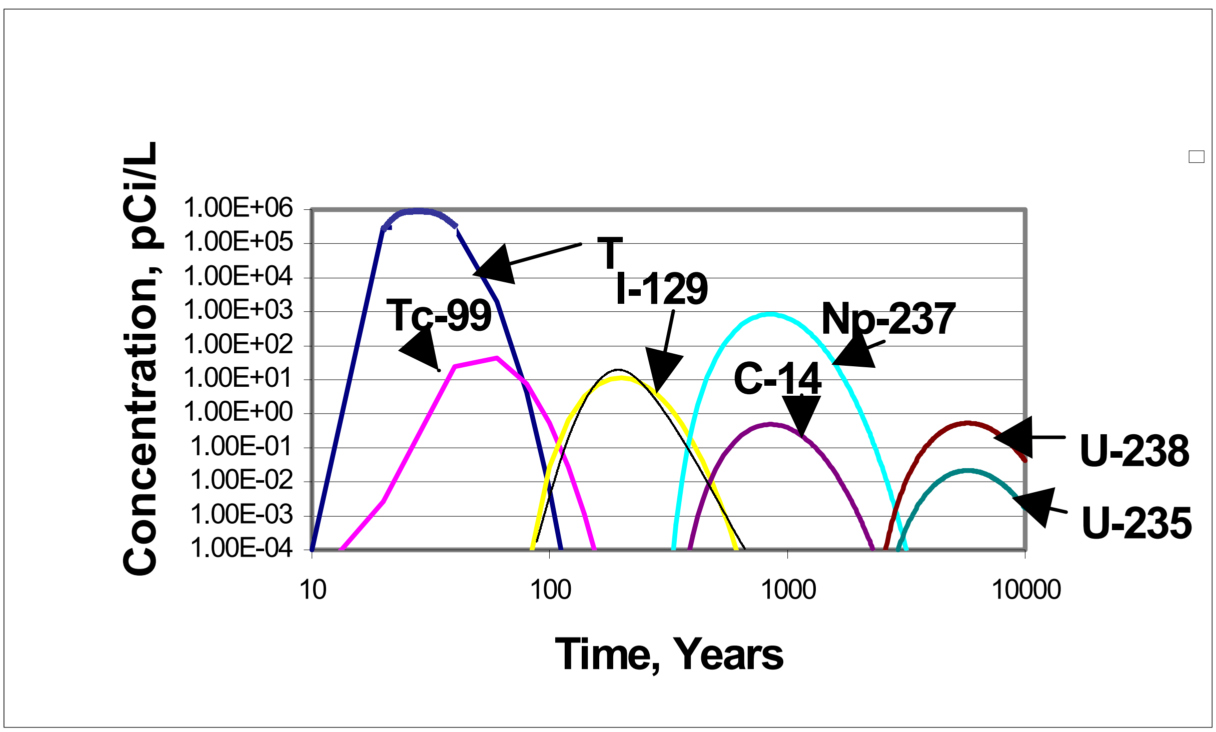


Appendix D.

Groundwater Transport and Stream Concentrations

Appendix D estimates the concentration of radionuclides, stable chemicals, and volatile organic compounds (constituents of interest [COI] as defined by Ref. D.1) in Fourmile Branch from the ORWBG seepage. It also estimates the concentrations of other nuclides from the Burial Ground that would be present at the time of each nuclide's maximum concentration. Estimates were calculated using inventories and locations of chemicals provided in the CMS/FS (Ref. D.1). An ISPR panel estimated the concentrations using a mathematical model (Appendix C). This Appendix presents all the nuclides on one graph (Figure D-1) so that the reader can determine when various nuclides would be present in relation to each other. (This figure is a log-log chart and shows the concentrations from 10 to 10,000 years and concentrations from one million to one ten thousandth of a pico-curie per liter.) The estimates established using the ISPR model were used in conjunction with the average mean flow of Fourmile Branch and the Savannah River (based on 10 year average flow; See Appendix C, page 36) to calculate expected concentrations at several locations downstream of the Burial Ground and of SRS. Appendix E of this document calculates potential doses to receptors from those estimated downstream concentrations.

Figure D-1
Radionuclide Concentration in Fourmile Branch



The model (Appendix C) calculates a vertically averaged concentration over the plume thickness as a function of time and location, with the contamination moving in the direction of the aquifer flow. In other words contaminant concentrations were spread across a horizontal plane source of the dimensions of the burial ground for all contaminants, with uniform flow through the vadose zone and the water table aquifer toward Fourmile Branch. The model assumed that movement of the contaminants was planar and not along a single straight line, and that the contaminants entered the creek along a plane and not at a single point. This assumption results in the calculation of the average concentration (of any contaminant) along that reach of the creek adjacent to the seepline. It used flow rate parameters defined in the CMS/FS. The model uses the entire inventory of waste in the burial ground, as was used in the CMS/FS, to calculate concentrations but assumed that all waste was put into the ground in 1960, which is approximately the mid-point of the active life of the burial ground. Therefore, for purposes of the model the initiation of decay and movement is assumed to have begun in 1960 and 1960 represents time 0 on figures associated with this Appendix.

The CMS/FS also modeled nuclide concentrations in Fourmile Branch. Rather than assuming a horizontal plane as the source and planar movement, it divided the burial ground into sectors and assumed a straight linear flow from that sector in the burial ground to a point in the creek the shortest distance from the burial ground sector. Thus the CMS/FS modeled a maximum concentration at a single point in the creek.

The FG felt that assuming a maximum concentration at a single point in the creek and calculating doses using that peak concentration was unnecessarily conservative. For this reason, they requested that the ISPR develop a model that more accurately reflects the average movement of contaminants from the burial ground to the creek.

Table D-1 presents the year when each radionuclide would be at maximum concentration in Fourmile Branch near the seep (Figure D-2). It also presents other nuclides that would be present at Fourmile Branch from the ORWBG in meaningful concentrations during the same time period. In addition to times of peak concentration, there are times in the future when several nuclides could be present concurrently, though none would be at their peak concentrations. The most significant of these periods is between 2,360 and 2,560 years in the future when carbon-14, iodine-129, and neptunium-237 would all be present in the creek. Table D-2 presents some examples of these instances. Based on concentrations in Fourmile Branch near the seep and dilution with increased flow, downstream concentrations were calculated. These are presented in Table D-3 for select locations in Fourmile Branch and the Savannah River. These three tables give years as calendar years for simplicity of understanding. The figures give time in years after 1960.

Some nuclides will decay away before they reach Fourmile Branch. These include cesium-137, cobalt-60, strontium-90, and plutonium-238. Downstream receptors will not be exposed to concentrations of these nuclides. The model calculated concentrations to year 11960 or 10,000 years after the date the model assumed waste was in the burial ground and decay was initiated.

Table D-1
Maximum Concentrations of Radionuclides from the Old Radioactive Waste Burial Ground at the Fourmile Branch Seepline.

Year	Radionuclide with Maximum Concentration in That Year	Concentration At Fourmile Branch Seepline (pCi/L)	Other Radionuclides Present in the Time period	Concentrations At Fourmile Branch Seepline (pCi/L)
1989	Tritium	870,000	Techentium-99	0.0026
2020	Technetium-99	44	Tritium	2000
2160	Iodine-129	12	None	
2800	Carbon-14	840	Neptunium-237	0.49
7660-7740[a]	Uranium-238	0.54	Uranium-235	0.022
7660-7740	Uranium-235	0.022	Uranium-238	0.54

[a] Both U-235 and U-238 peak between the years 7660 and 7640

Table D-2
Years when More Than Two Radionuclides Would be Present in Fourmile Branch Seepline in Meaningful Concentrations.

Year	Radionuclides Present	Concentrations (pCi/L)
2060	Tritium	0.0062
	Technetium-99	0.055
	Iodine-129	0.028
2360	Iodine-129	0.015
	Carbon-14	0.49
	Neptunium-237	0.0027
2460	Iodine-129	0.0052
	Carbon-14	43
	Neptunium0237	0.024
2560	Iodine-129	0.00015
	Carbon-14	270
	Neptunium-237	0.15

Figure D-2
SRS Map Showing Location of Calculated Concentrations

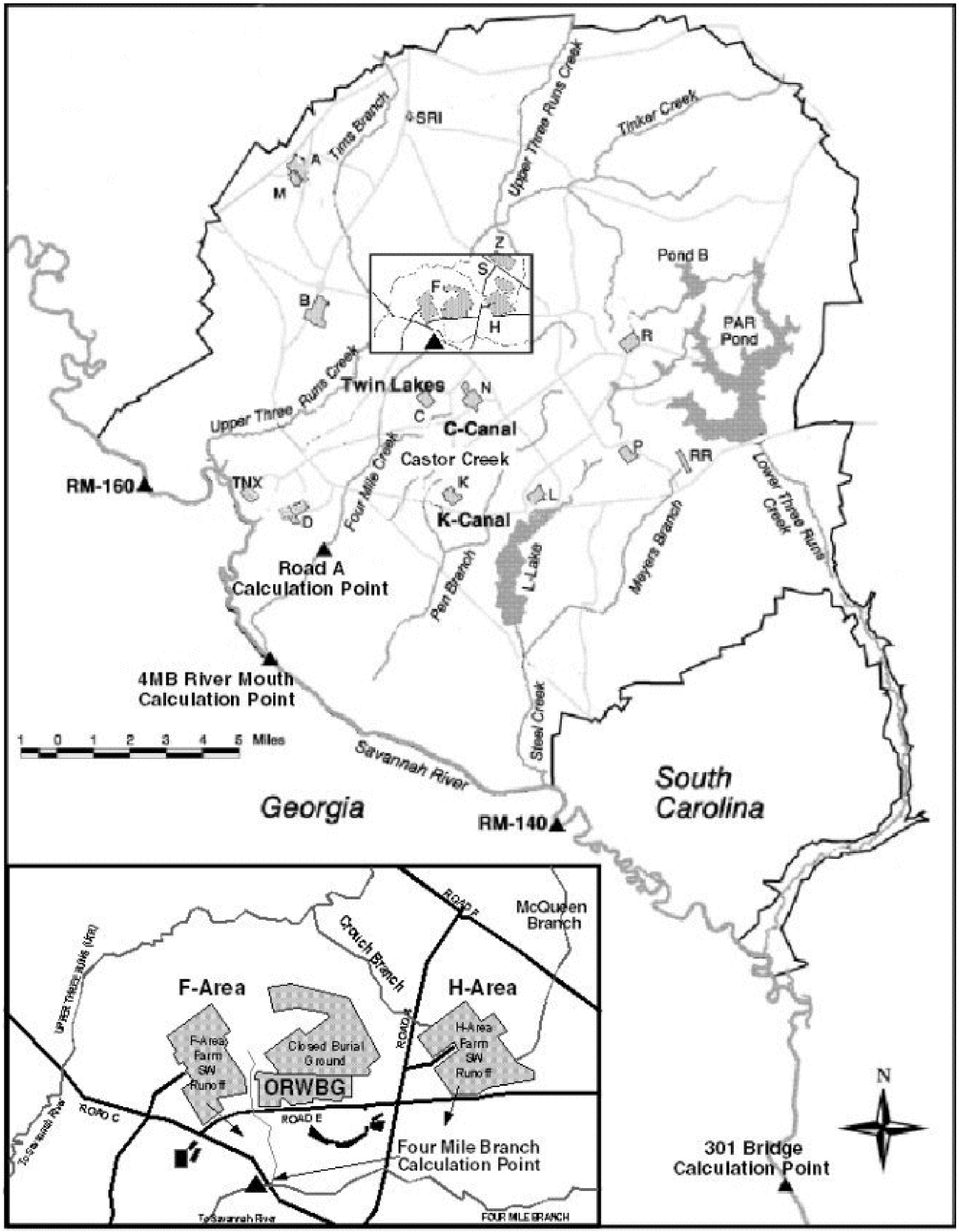


Table D-3
Concentrations of Nuclides at Locations Downstream of Fourmile Branch at the Seepline and in the Savannah River.

Year	Nuclide	Concentration* (pCi/L) at			
		Road A on SRS	Savannah River at Mouth of Fourmile Branch	Savannah River at 301 Bridge	Port Wentworth Water Intake
2020	Technetium-99	11	0.034	0.032	0.028
	Tritium	483	1.5	1.5	1.3
2060	Technetium-99	0.13	0.00043	$4.0x10^{-4}$	$3.6x10^{-4}$
	Tritium	0.0015	4.8×10^{-6}	4.6×10^{-6}	4.0×10^{-6}
	Iodine-129	0.0067	2.2×10^{-5}	2.0×10^{-5}	1.8×10^{-5}
2160	Iodine-129	280	0.009	0.0085	0.0075
2360	Iodine-129	0.035	$1.1x10^{-4}$	$1.1x10^{-4}$	9.40×10^{-5}
	Carbon-14	0.12	0.0004	$3.6x10^{-4}$	$3.2x10^{-4}$
	Neptunium-237	6.6×10^{-5}	2.1×10^{-7}	2.0×10^{-7}	1.8×10^{-7}
2460	Iodine-129	0.0013	4.1×10^{-6}	3.8×10^{-6}	3.4×10^{-6}
	Carbon-14	10	0.033	0.031	0.028
	Neptunium-237	0.0058	1.9×10^{-5}	1.8×10^{-5}	1.5×10^{-5}
2560	Iodine-129	3.6×10^{-5}	1.2×10^{-7}	1.1×10^{-7}	9.7×10^{-8}
	Carbon-14	65	0.21	0.2	0.17
	Neptunium-237	0.037	$1.2x10^{-4}$	$1.1x10^{-4}$	9.8×10^{-5}
2800	Carbon-14	200	0.65	0.62	0.55
	Neptunium-237	0.12	$3.8x10^{-4}$	$3.6x10^{-4}$	$3.2x10^{-4}$
7660	Uranium-235	0.0053	1.7×10^{-5}	1.6×10^{-5}	1.4×10^{-5}
	Uranium-238	0.13	$4.2x10^{-4}$	$3.9x10^{-4}$	$3.5x10^{-4}$
7740	Uranium-235	0.0053	1.7×10^{-5}	1.6×10^{-5}	1.40×10^{-5}
	Uranium-238	0.13	$4.2x10^{-4}$	$3.9x10^{-4}$	$3.5x10^{-4}$

* Estimated based on flows at gauging stations in the Savannah River above and below Fourmile Branch.

Plutonium-239 wouldn't appear at the seep until approximately 32,000 years from today. The concentration in Fourmile Branch would increase steadily and reach a peak concentration 80,000 years from now. The peak concentration would be about 0.7 pCi/L. It would then decrease from this peak value over the following 100,000 years. This analysis is given in Appendix C computer output for Pu-239.

Peak mercury concentrations (1.37 μg/L) should occur between years 3560 and 3660 (Figure D-3 shows the peak concentration at 1,625 years hence). Peak lead concentrations (0.63 μg/L) would occur between approximately 16960 and 18960 (Figure D-4 shows the peak concentration at 16,375 years hence). Peak cadmium concentrations (0.327 μg/L) would occur around 2960 (Figure D-5 shows the peak concentration at 1,000 years hence). VOC concentrations of 10 μg/L should have appeared at the seep by about 1992 and are calculated to reach a maximum in 2012 (93 μg/L) then decrease until 2040 (Figure D-6).

Groundwater monitoring data do not show significant VOC being released from the seeps to Fourmile Branch. Significant VOCs are currently detected in the groundwater between the ORWBG and the seeps. Figure 1-4 of reference D.2 show VOC concentrations in excess of 300 μg/L just beyond the fence surrounding the ORWBG and a fairly significant stretch of the groundwater between the fence and the outcrop exceed 50 μg/L. (Section 3 of this report describes the VOC remedation planned for the SW plume.) The fact that the VOCs are not currently discharging into the Fourmile Branch seems to infer that some of the transport parameters (probably the K_d for VOC) are overestimated and transport is slower than projected.

Radionuclides and chemical releases occur during the same time periods. This can be seen by comparing Figure D-1 with Figures D-3 through D-6. To simplify this comparison Table D-4 compares the chemical release time periods with the radionuclide releases.

Table D-4
Chemical and Radionuclide Release Periods

Chemical Releases	Start Period	Completion Period	Radionuclides Released During the Same Time Period
VOC	1988	2060	Tritium and Technelium-99
Cadmium	2460	3960	Carbon-14, Iodine-129, and Neptunium-237
Mercury	2960	4960	Carbon-14 and Neptunium-239
Lead	11960	41960	Uranium-238 and Uranium-235

VOC = Volatile Organic Compound

Figure D-3
Mercury Concentration in Fourmile Branch

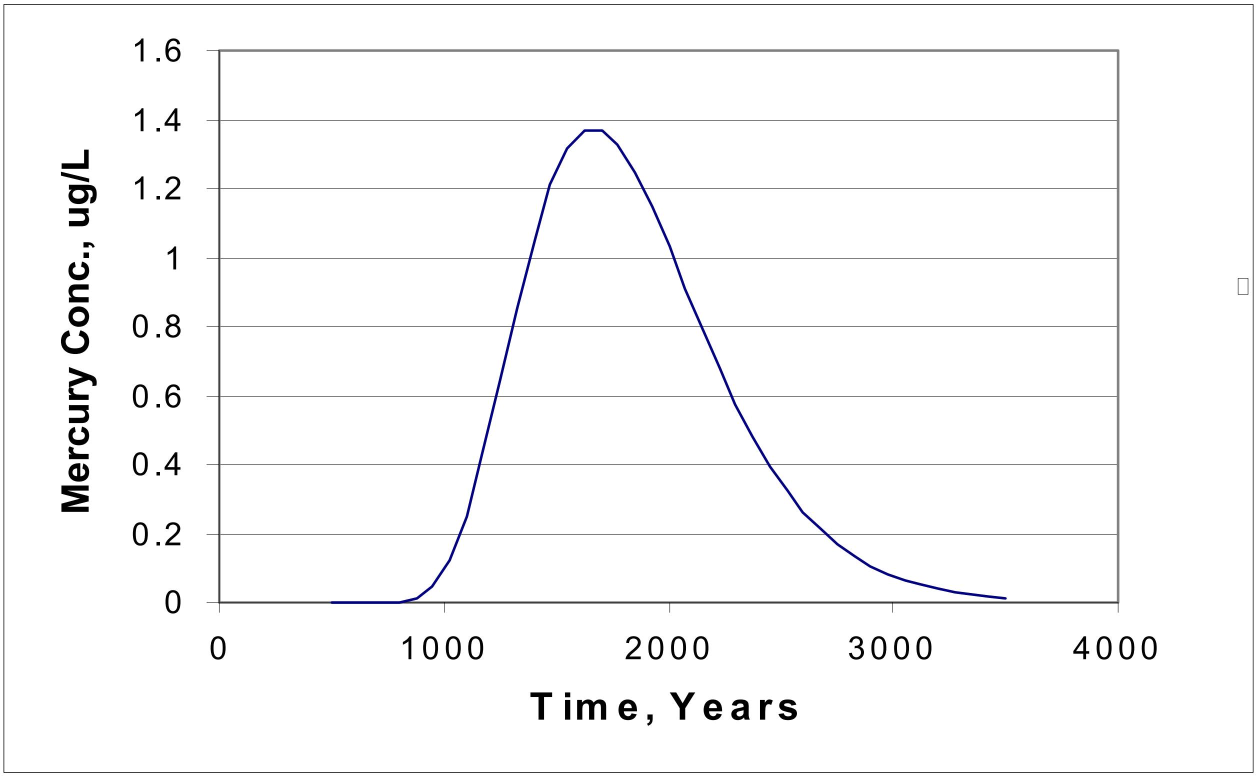


Figure D-4
Lead Concentration in Fourmile Branch

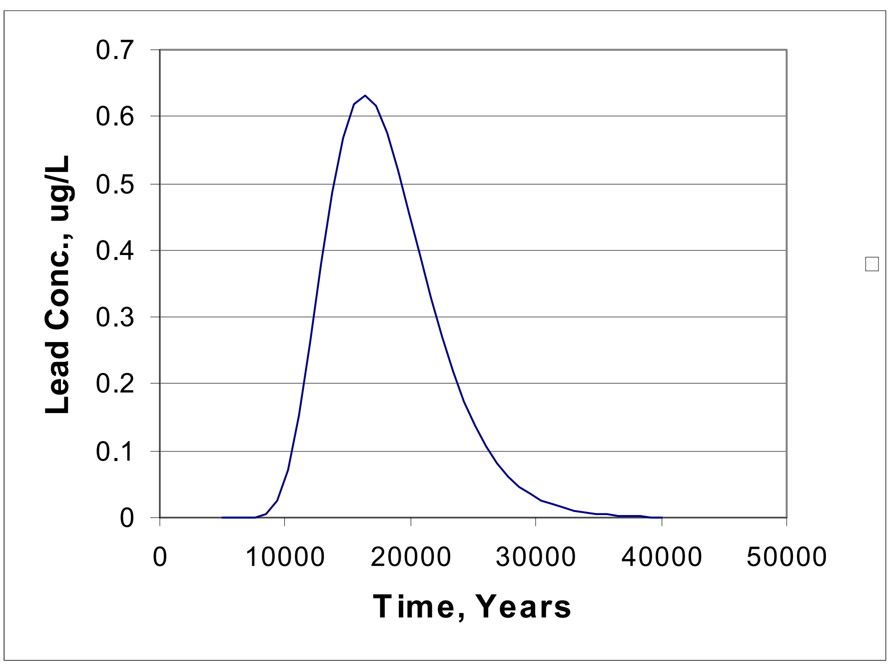


Figure D-5
Cadmium Concentration in Fourmile Branch

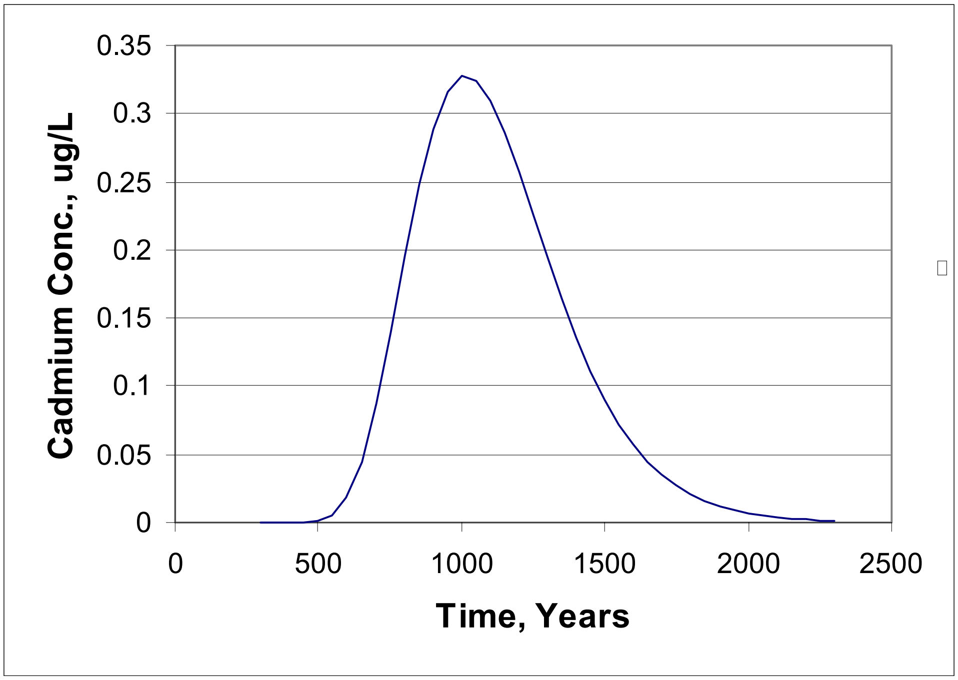
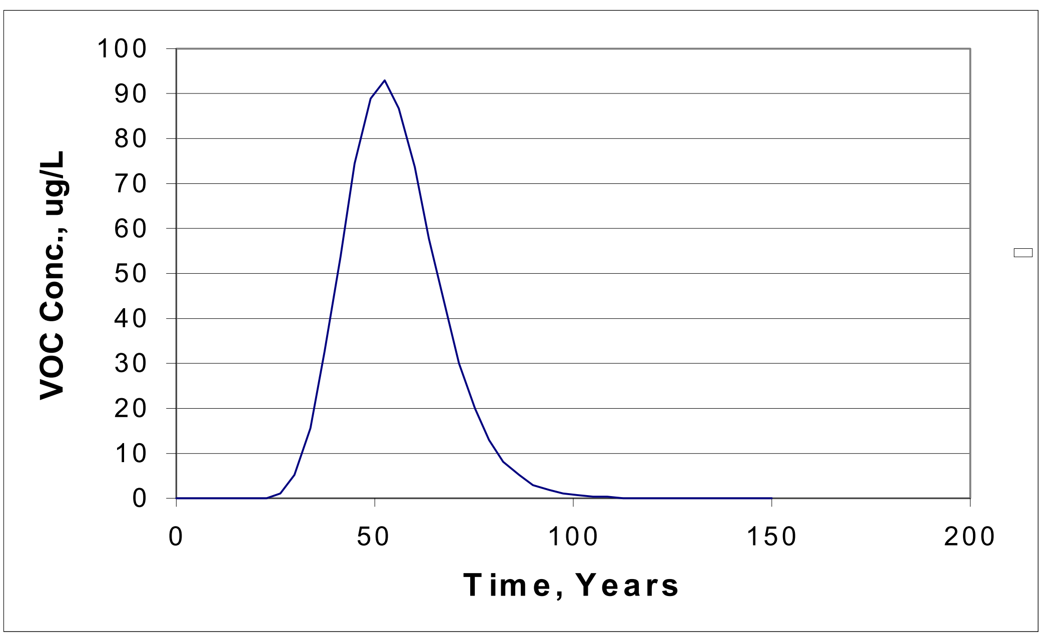


Figure D-6
VOC Concentration in Fourmile Branch



References for Appendix D

D.1 *"Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-E",* Westinghouse Savannah River Company, Report Number WSRC-RP-98-4012, Rev 0, March 1999.

D.2 *"Environmental Assessment for the Interim Measures for the Mixed Waste Management Facility, Groundwater at the Burial Ground Complex at the Savannah River Site"*, DOE/EA-1302, December 1999.

Appendix E.

Human Exposures and Potential Dose from Radionuclides Released from ORWBG

This appendix presents radiological exposures that could be encountered by drinking water from Fourmile Branch and the Savannah River with the calculated concentrations of radionuclides expected to be released from the ORWBG. The dose calculations assumed that a person drank 2L per day of water from the source locations presented in Appendix D. The expected drinking water dose rates are calculated and compared with the present regulatory limits.

E.1 Exposures from Drinking Contaminated Water in the Near Term (200 years or less)

This section provides information needed to estimate the near-term consequences of the ORWBG radionuclides flushed to Fourmile Branch, then to the Savannah River. Dose rates are calculated using the process defined by the ISPR on pages 24 - 28 of Appendix C. Table E-1 provides the dose conversion factors provided in that Appendix for the radionuclides that come from the ORWBG during the ISPR 10,000 year analysis period. Table E-2 gives the total 50-year committed dose from internal exposure from all radionuclides released from the ORWBG if all of an individual's drinking water were from that one source. (SRS releases from facilities other than the ORWBG are not included.) During this period, the primary radionuclides that reach the Fourmile Branch are tritium, technetium-99 and iodine-129.

Table E-1
Dose Conversion Factors Used in Analysis

Radionuclide	Dose Conversion Factors	
	Sv/Bq	mrem/yr
Tritium	1.73×10^{-11}	6.41×10^{1}
Carbon-14	5.64×10^{-10}	2.09×10^{3}
Technetium-99	3.95×10^{-10}	1.46×10^{3}
Iodine-129	7.46×10^{-8}	2.76×10^{5}
Neptunium-237	1.2×10^{-6}	4.44×10^{6}
Uranium-235	7.19×10^{-8}	2.66×10^{5}
Uranium-238	6.88×10^{-8}	2.55×10^{5}

Table E-2
Dose Rate from Drinking Water with ORWBG Contamination during the Near Term (mrem/yr)

Year	Fourmile Branch at the ORWBG Seepline (mrem/yr)	Road A (mrem/yr)	Savannah River at Mouth of Fourmile Branch (mrem/yr)	Savannah River at Highway 301 Bridge (mrem/yr)	Port Wentworth Water Intake (mrem/yr)
1980	15	3.5	0.012	0.011	0.010
1989	53	13.2	0.041	0.038	0.034
2000	14	3.5	0.011	0.010	0.009
2020	0.15	0.04	1.2×10^{-4}	1.1×10^{-4}	1×10^{-4}
2060	7×10^{-3}	2×10^{-3}	5×10^{-6}	4×10^{-6}	1×10^{-6}
2160	3	0.62	2×10^{-3}	2×10^{-3}	1.7×10^{-3}

Figure E-1 shows the contribution to dose rate from each of the major radionuclides and the total in Fourmile Branch near the seep line between 1980 and 2160. As can be seen from this figure, after the present time tritium decreases, technetium-99 peaks then decreases, and iodine-129 becomes the major source of the dose near the end of this time period. Figure E-2 shows the dose rate resulting from drinking water at the four locations. As in Appendix D, time 0 on these figures is the year 1960. The peak tritium occurred in 1989 as shown in Table E-2.

Figure E-1
Dose Rate (mrem/yr) from Drinking Fourmile Branch Water during the Near Term

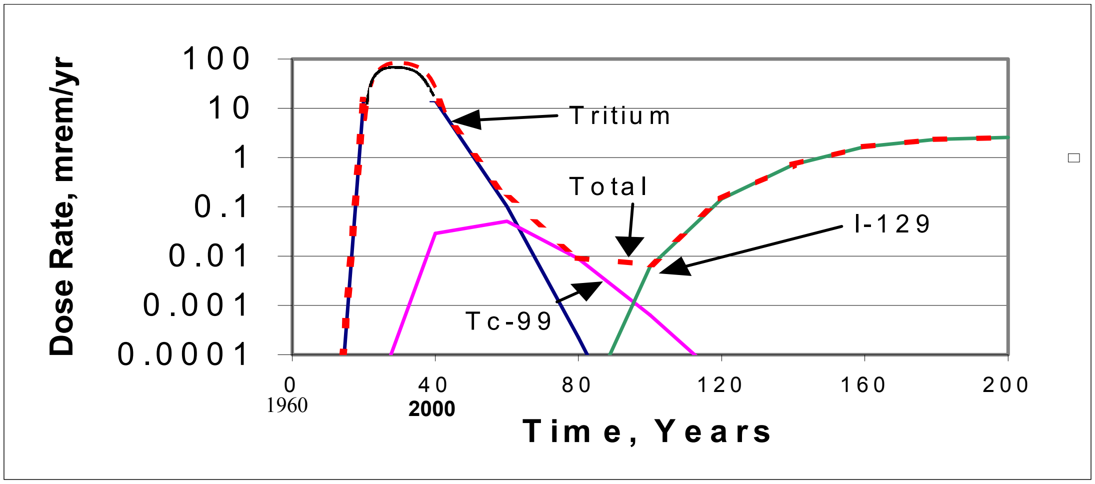
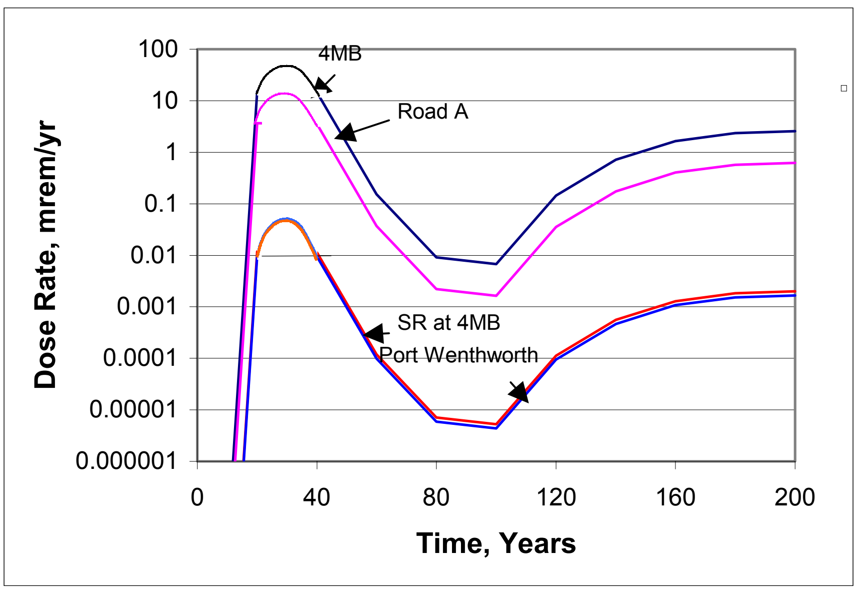


Figure E-2
Dose Rate (mrem/yr) from Drinking Water Contaminated with ORWBG Releases During the Near Term



E.2 Dose from Drinking Contaminated Water in the Future (after 200 years)

This section presents the dose rates for the remainder of the 10,000 year analytical period if water from the specified locations was used by an individual exclusively for his drinking water, as was done in Section E.1 for the near-term. The dates in Table E-3 correspond to peak doses shown in Figure D-3. They represent periods of maximum dose rates. The specific radionuclides and their dose contributions, and the total dose are given in the table.

As discussed in Appendix D, plutonium-239 wouldn’t appear in the branch until approximately 32,000 years from now. From that time forward, the concentration, and thus the dose, would increase steadily to a peak dose rate of 0.73 mrem/yr about 80,000 years from now. The plutonium contribution would then decrease over the next 100,000 years.

Figures E-3 and E-4 show the ORWBG contaminant dose rates for this future time period. Figure E-3 shows the contaminant contribution and the total dose if Fourmile Branch waters were the only drinking water source. Figure E-4 shows the total dose at the four locations downstream of the ORWBG seepline used in Figure E-2. (Both axis in Figures E-3 and E-4 are logarithmic.)

Table E-3
Doses from Drinking Contaminated Waters from ORWBG in the Future

Year	Nuclide	Dose (mrem/yr)			
		Road A	Savannah River at Mouth of Fourmile Branch[a]	Savannah River at 301 Bridge	Port Wentworth Water Intake
2020	Technetium-99	0.012	4.0×10^{-5}	3.8×10^{-5}	3.3×10^{-5}
	Tritium	0.025	8.0×10^{-5}	7.5×10^{-5}	6.6×10^{-5}
	Total Dose[b]	0.037	0.00012	0.00011	9.9×10^{-5}
2060	Technetium-99	0.00015	5.0×10^{-7}	4.7×10^{-7}	4.2×10^{-7}
	Tritium	7.8×10^{-8}	2.5×10^{-10}	2.3×10^{-10}	2.1×10^{-10}
	Iodine-129	0.0015	4.8×10^{-6}	4.5×10^{-6}	4.0×10^{-6}
	Total Dose[b]	0.0017	5.8×10^{-6}	5.0×10^{-6}	4.4×10^{-6}
2160	Iodine-129	0.62	0.002	0.0019	0.0017
2360	Iodine-129	0.0078	2.5×10^{-5}	2.4×10^{-5}	2.1×10^{-5}
	Carbon-14	0.0002	$6.4x10^{-7}$	6.0×10^{-7}	5.3×10^{-7}
	Neptunium-237	$2.3x10^{-4}$	$7.5x10^{-7}$	7.1×10^{-7}	6.2×10^{-7}
	Total Dose[b]	0.0082	0.002	2.5×10^{-5}	2.2×10^{-5}
2460	Iodine-129	$2.8x10^{-4}$	9.0×10^{-7}	8.5×10^{-7}	7.5×10^{-7}
	Carbon-14	0.017	5.6×10^{-5}	5.2×10^{-5}	4.6×10^{-5}
	Neptunium-237	0.021	6.6×10^{-5}	6.2×10^{-5}	5.5×10^{-5}
	Total Dose[b]	0.038	$1.2x10^{-4}$	0.00012	0.00010
2560	Iodine-129	8.1×10^{-6}	2.6×10^{-8}	2.4×10^{-8}	2.2×10^{-8}
	Carbon-14	0.11	$3.5x10^{-4}$	$3.3x10^{-4}$	$3.0x10^{-4}$
	Neptunium-237	0.13	$4.2x10^{-4}$	$3.9x10^{-4}$	$3.5x10^{-4}$
	Total Dose[b]	0.24	$7.7x10^{-4}$	$7.2x10^{-4}$	$6.4x10^{-4}$
2800	Carbon-14	0.34	0.0011	0.0010	$9.2x10^{-4}$
	Neptunium-237	0.42	0.0014	0.0013	0.0011
	Total Dose[b]	0.77	0.0025	0.0023	0.0021
7660	Uranium-235	0.0011	3.2×10^{-6}	3.4×10^{-6}	3.0×10^{-6}
	Uranium-238	0.027	8.5×10^{-5}	8.1×10^{-5}	7.1×10^{-5}
	Total Dose[b]	0.028	8.9×10^{-5}	8.4×10^{-5}	7.4×10^{-5}
7740	Uranium-235	0.0011	3.6×10^{-6}	3.4×10^{-6}	3.0×10^{-6}
	Uranium-238	0.027	8.5×10^{-5}	8.1×10^{-5}	7.1×10^{-5}
	Total Dose[b]	0.028	8.9×10^{-5}	8.4×10^{-5}	7.4×10^{-5}

a Estimated based on flows at gauging stations above and below Fourmile Branch
b Dose from all ORWBG nuclides present in the water, not just the nuclides reported in this table

Figure E-3
Dose Rate (mrem/yr) from Drinking Fourmile Branch Water during the Long Time

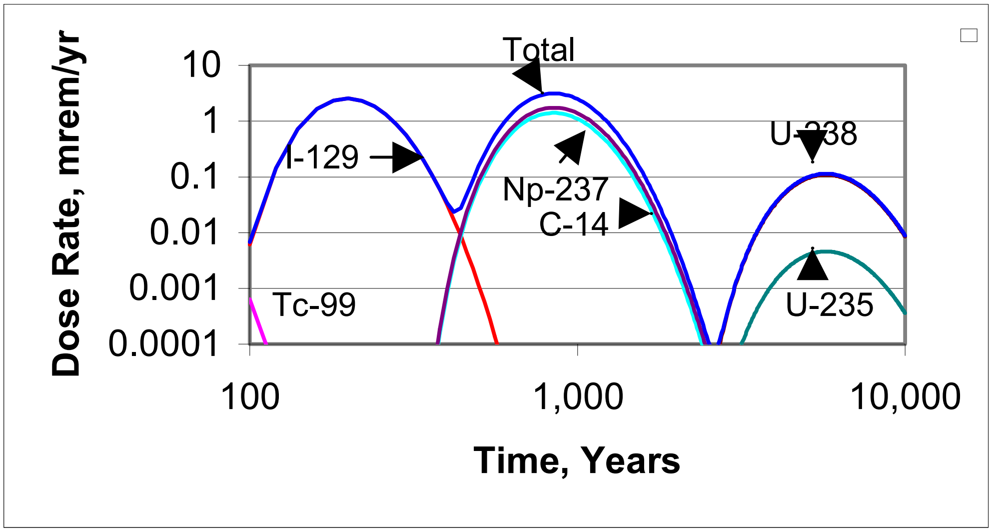
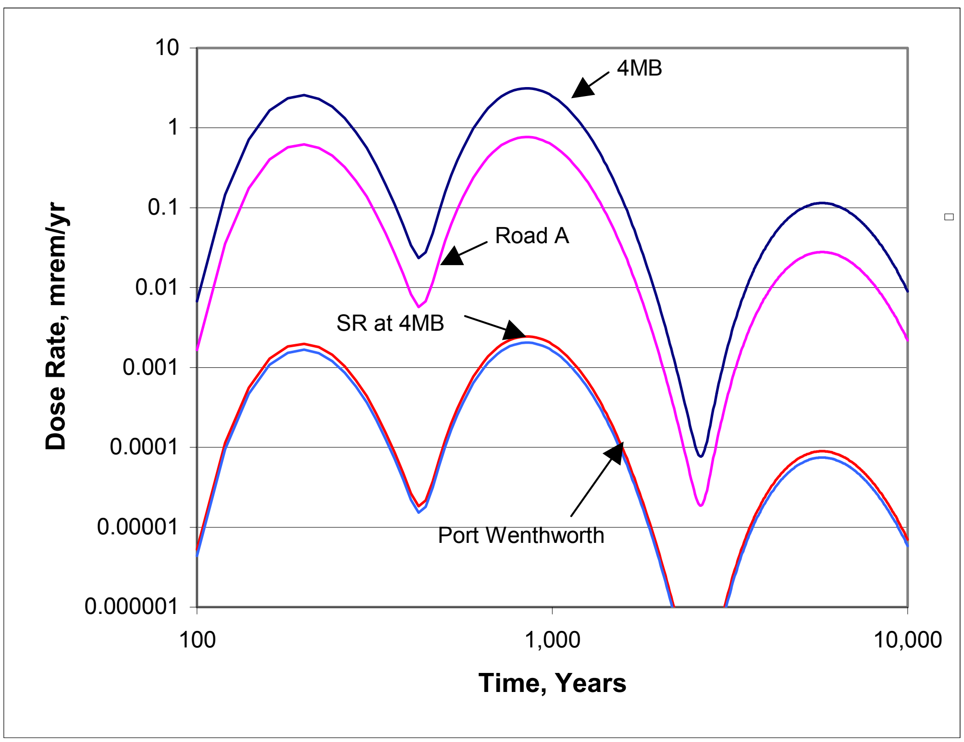


Figure E-4
Dose Rate (mrem/yr) from Drinking Water Contaminated with ORWBG Releases During the Long Time



E.3 Regulatory Limits

The U.S. Environmental Protection Agency established primary drinking water regulations as part of 40 CFR 141 (Ref. E.5). This regulation is applicable to public drinking water suppliers. As defined in the regulation the smallest supplier is a community water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents. This regulation does not apply to a farmer's water source.

Subpart B of this standard quantifies maximum contaminant levels allowed. Paragraphs 141.11 and 141.12 specify the maximum concentration of inorganic chemicals and trihalomethanes respectively. Section 141.15 and 141.16 specify the maximum allowable radon and alpha, beta and photon levels respectively. The gross alpha limit is specified at 15 pCi/L (after radon has been removed) and beta and photon limits are set such that an annual dose to the whole body or to any organ shall not exceed 4 mrem/yr.

South Carolina Department of Health and Environmental Control have adopted similar regulations but apply them to all "waters of the state". These regulations are discussed in greater detail in Section 9 of this report.

E.4 Comparison with Regulatory Limits and Conclusions

The regulatory dose limit established by EPA and adhered to by SCDHEC is 4 mrem per year from drinking water. Currently that dose rate is exceeded at Fourmile Branch at the seepline, and met at Road A on the SRS (Table E-2) due to the concentrations of tritium in the surface water. Neither of these locations is accessible to the public as a source of drinking water, and will not be for as long as the SRS remains under active institutional controls. Currently the dose an individual would receive from drinking only Savannah River water at the mouth of Fourmile Branch is 0.011 mrem per year, well below the drinking water regulatory limit. In less than twenty years, the doses from Fourmile Branch at the seep, and at Road A will be much less than 4 mrem per year because the concentrations of tritium are decreasing (Table E-2). Therefore the FG concludes that additional remediation to reduce the current drinking water dose is not warranted.

In the future, the estimated maximum concentration an individual could get (from drinking the water at Road A) for a single year is 0.77 mrem in about the year 2800 (Table E-3). That is the highest calculated 50-year committed dose at any of the four downstream locations at any time during the 10,000-year analysis period. Because this annual dose is well below the regulatory limit of 4 mrem, the FG concludes that remediation to reduce the future risk from drinking water is not necessary. See Appendix H for a discussion of potential health effects associated with these levels of exposure.

References for Appendix E

E.1 *"Environmental Report for 1999",* Environmental Monitoring Section of Environmental Protection Section, WSRC-TR-99-00299, Westinghouse Savannah River Company.

E.2 *"Limitations of Exposure to Ionizing Radiation",* National Council on Radiation Protection and Measurements, Report Number 116, 1993, Washington, DC.

E.3 1998 National Vital Statistics Report, Volume 47, Number 4*, "Births and Deaths: Preliminary Data for 1997",* US Department of Health and Human Services, Washington, DC, October 7, 1998.

E.4 *"High-Level Waste Tank Closure, Draft Environmental Impact Statement",* Department of Energy, EIS Number DOE/EIS-0303D, November 2000.

E.5 Title 40 – Protection of the Environment – Code of Federal Regulations, Part 141 – National Primary Drinking Water Regulations, 40-CFR-141.

Appendix F.

Human Exposure and Potential Dose from Surface Occupation of the ORWBG Site

Environmental remediation of the ORWBG requires consideration of risk of human occupation of the burial ground site over near- and long-term time frames. Prevalent among these risks are the radiation exposures incurred by onsite workers in surveillance and maintenance operations during the time of active institutional control (assumed 150 to 300 years) and by members of the public with access to the site during subsequent times (up to 10,000 years in this analysis). This appendix projects radiation exposures for the on-site worker currently as measured using the monitoring data at the site. Long-term exposures are estimated for individuals potentially occupying and performing agricultural activities on the site of the ORWBG. Occupancy of the site at sometime in the future assumes failure of passive institutional controls (IC) (fencing, markers, public records and archival restrictions) imposed to restrict public access to and use of the burial ground. The agricultural scenario establishes a chronic exposure for the occupant who lives on the site year-round for one year. Projection of the exposures for other scenarios is presented in the Intruder Analysis in Section 4 of this report and Appendix G and to a lesser degree in the CMS/FS (Ref. F.1).

F.1 Near-Term Radiation Exposures

The radiation exposures to on-site workers during the period of active IC can be assumed to occur during routine maintenance activities, including inspection and repair of the ORWBG surface cap, service of perimeter monitoring wells, control of surface water runoff and resulting erosion, and upkeep of the prescribed vegetative cover. Routine air monitoring of the ORWBG complex has shown radiation exposures in the range of 82 – 239 mrem/yr with an average of about 120 mrem/yr as measured by thermoluminesent dosimeters (TLD) recording beta-gamma radiation (Ref. F.2). These exposures are approximately equivalent to the average U. S. population exposure of about 300 mrem/yr, less the 200 mrem/yr exposure to alpha radiation from radon sources in geologic and structural features in the environment (or 100 mrem/year from natural sources other than radon) (Ref. F.3). Current monitoring results at the ORWBG indicate that workers receive no additional dose from the radionuclides buried in the ORWBG.

F.2 Radiation Exposure Beyond Active Institutional Control

Two factors potentially contribute to the radiation exposure incurred by an occupant of the burial ground site after the cessation of active IC. These are (1) erosion of the surface cap such that direct exposure to waste constituents could occur and (2) the presence of localized high concentrations of waste constituents (hot spots) to which the site occupant could be exposed.

Erosion of the ORWBG Cap

Concern over chronic exposure to a long-term (year or more) occupant of the burial ground site is centered on the fate of hot spot waste concentrations over extended time periods (up to 10,000 years). Within this time period, the occurrence of erosion potentially uncovering the buried waste requires quantitative evaluation. The CMS/FS analysis employs an erosion rate of 1.4 mm/yr, which could result in penetration of the minimum 8-foot cap on the ORWBG in about 1,750 years. Before this time, surface radiation exposures, as currently measured, should prevail for the ORWBG. Erosion of the burial ground cover to directly expose the waste would significantly increase the chronic exposure of an occupant of the site. Analysis of projected exposure for hot spot concentrations presented in the CMS/FS provide a measure of this increased exposure.

Hot Spot Radiation Exposures

Detailed review of the data presented in the CMS/FS documentation has identified hot spots containing carbon-14 and plutonium-239 as the most significant potential contributors to radiation exposures resulting from increased erosion after cessation of IC. As reported in Appendix G, the hot spots containing these waste constituents should be exposed in about 1,750 years. Though data for 1,750 years hence is not available, the significant increase between 1,000 and 3,000 years support this correlation of exposure of the hot spots by erosion to increased radiation. Maximum 50-year committed dose, in excess of 930 mrem/yr, are projected to occur 3,000 years hence and then slowly decrease, probably due to radioactive decay or transport of the waste by erosion. Recognizing that any individual would receive a dose from natural background of 120 mrem, the incremental dose this individual might receive from the hot spot could be 810 mrem. (This 810 mrem incremental value is used elsewhere in this report.) Other hot spots locations have relatively low potential dose rates, due to rapid depletion of the radionuclides by decay and radionuclide leaching.

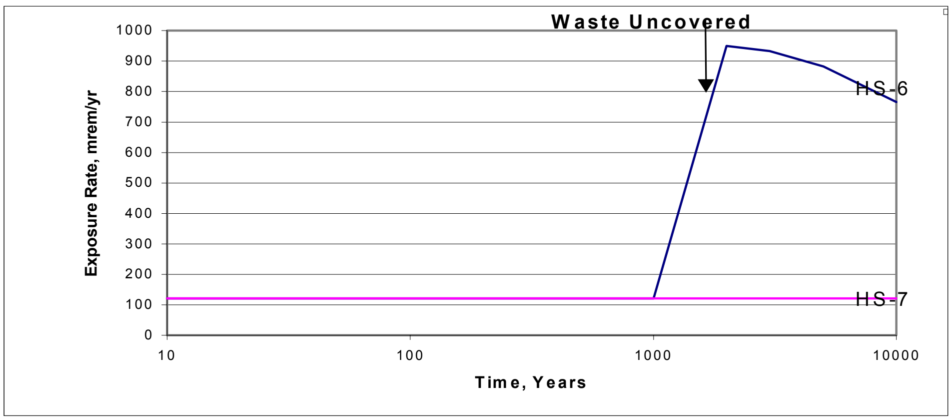
Figure F-1 shows the effect of severe erosion. Two hot spot areas were selected as examples. They are HS-6 and HS-7 from the CMS/FS. HS-6 contains plutonium-239 at an average concentration of 141 ηCi Pu/gram of soil. The significant increase in dose rate (Figure F-1) occurs when erosion uncovers the waste. The dose rates for HS-6 values were obtained from Appendix B of Reference F.1 and is defined in that report as "agricultural, air" dose rates. The FG assumes this is an inhalation of radionuclides from resuspended contaminants in the soil. HS-7 was selected to show the long-term consequence of surface occupation of ORWBG areas that contain no appreciable long-lived radionuclides.

Remediation of Radiation Risk

The FG believes that the potential for relatively high radiation dose rates from surface occupation of the ORWBG site after active IC mandates remedial measures to impede erosion of the burial ground cap. Although the low probability of exposure substantially reduces the projected risk, the high consequence of such an exposure suggests the need for erosion control. See Appendix H for a discussion of potential health risks associated with these levels of exposure.

Reduction of the rate of erosion of the cap is potentially achievable by adding a protective vegetative cover to minimize the erosion and prevent establishment of deep-rooted plants on the cover. In one treatment scenario the burial ground cap would be

Figure F-1
ORWBG Surface Radiation Exposure



planted with two bamboo species, as planned for the E-Area Vaults. The bamboo species, once established, would grow six to eight feet tall and form a dense top cover shading the natural succession of native trees. This type cover is expected to reduce the soil erosion to a rate projected for a natural succession forest, equivalent to 0.007 mm/yr. At this erosion rate, several tens of thousands of years would be required to uncover the ORWBG waste constituents. The lower curve on Figure F-1 illustrates the impact of surface stabilization to minimize surface erosion. The benefit of this control is illustrated by the difference between the two curves on Figure F-1.

The surface exposure expected for the burial cap, as it now exists, provides additional justification for the Focus Group recommendation G-3. See discussion on page G-5.

F.3 Impact from Burrowing Animals and Insects

Most animals and insects do not penetrate the depth of the cover that currently exists over the ORWBG. The only intrusion of concern would be by the Florida Harvester Ant (Ref. F.4). This ant species generally burrows down about 6 feet. Studies have shown that 5 percent of these ants can burrow deeper and could bring a small amount of contaminated soil to the surface. This small amount of contamination may cause small increases in exposure to individuals on the surface of the ORWBG. The magnitude of this exposure increase is not estimated here because of the large uncertainties in infestation of the SRS area by these ants, and future use of the land. The Focus Group concludes that the consequence of these deep burrowing animals/insects has an inconsequential impact on the ORWBG future.

References for Appendix F

F.1 *"Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-G"*, Westinghouse Savannah River Company, Report Number WSRC-RP-98-4012, Rev. O, March 1999.

F.2 *"Savannah River Site Environmental Report for 1997",* WSRC-TR-97-00322, page 39, Westinghouse Savannah River Company, Aiken, SC.

"Savannah River Site Environmental Report for 1999", WSRC-TR-99-00301, Westinghouse Savannah River Company, Aiken, SC.

F.3 *"Potential Human Health Risk from Low Level Radiation Doses",* by Tim Jannik, Presentation to the ORWBG Focus Group, May 31, 2000.

F.4 *"Relevance of Biotic Pathways to the Long-Term Regulation of Nuclear Waste Disposal, Phase II"*, by D. H. McKenzie et.al, Final Report, Pacific Northwest Laboratory, Richland, WA, Report Number NUREG/CR-2675 or PNL-4241, 1986.

Appendix G.
Human Exposure and Potential Dose from Intruder Occupation of the ORWBG and Land Between the ORWBG and Fourmile Branch

G.1 Summary Conclusion

This appendix attempts to determine potential exposure to people who could dig up the waste buried in the ORWBG and use it and the potential exposure to people who could drink the groundwater between the ORWBG and Fourmile Branch.

Summary/Conclusion/Recommendation

Based upon the analysis and considerations given in this Appendix, the FG reach the following conclusions:

1. The stewardship for the ORWBG should include both active and passive controls. Active controls will prevent members of the public from occupying the site of the ORWBG and digging into the waste. The analysis in this Appendix assumed active controls would be in place 150 to 300 years after cessation of SRS operations. During this time a dose from digging into the waste might be as high as 100 rem, but the probability would be essentially nil because of active controls. Thus, there is no risk to the intruder. Active IC is currently practiced but there is no long-term requirement to ensure these controls will remain in place. The FG recommends that SRS institutionalize the time requirement for the active IC for the ORWBG and the lands between the ORWGB and Fourmile Branch **(Recommendation G-1)**

2. The passive controls for the ORWBG required by the SRS stewardship program should include fencing, permanent markers to tell of the buried hazard, and publicly recorded and archived restrictions (including easements, deed notification, deed restrictions, lease requirements, covenants, etc.). Passive controls will not require active maintenance (e.g., mowing, erosion control, etc.) The FG recommends that SRS establish an approach for passive IC for the ORWBG that protects the public from these buried hazards and restricts access to the lands between the ORWBG and the seepline. The FG additionally recommends that specific passive controls be institutionalized within the next 5 years **(Recommendation G-2).** These controls should have both short-term and long-term components with adequate specificity and technical support to ensure their continued implementation

3. One of the passive controls required should be a land management plan that ensures an erosion control strategy to minimize erosion and to ensure that deep-rooted plants do not encroach on the surface of the ORWBG. This is discussed in greater detail in Section G.3. Another passive control should make it clear to future generations that the groundwater under the area between the ORWBG and Fourmile Branch may be hazardous. This is discussed in Section G.5

4. An inadvertent intrusion after 300 years is a low consequence event that would cause no serious health effects.

5. The probability of failure of passive IC is expected to be low, but over the 10,000-year analysis period, failure is expected to occur. The FG concluded that it is appropriate to assume that any intrusion would be detected by the appropriate authorities and remediation implemented within one year. Multiple failures involving the same individual or family is not considered credible.

6. Inadvertent intrusion should cause no serious health effects.

G.2 Background and Approach Used

Active and Passive Controls

The analyses considered in this appendix assumes the lands of the present ORWBG and the lands between the ORWBG and the points of groundwater out-cropping into Fourmile Branch will remain under long-term stewardship (active or passive) for as long as required to maintain safety of operating staff and the public. As indicated in Ref. G.1, "long-term stewardship includes all activities, environmental monitoring, site maintenance, application and enforcement of institutional controls and information management required to protect human health and the environment from hazards remaining at DOE sites after cleanup is completed." Reference G.1 identifies a key element of the SRS stewardship program as the use of institutional control to ensure that land use restrictions are maintained. SRS has been subdivided into three land use zones. They are General Support Zone, Site Industrial Support Zone, and Site Industrial Zone. The ORWBG is located in the Site Industrial Zone, near the center of the Site, surrounded by a safety and security buffer area. The Site Industrial Zone contains all of the facilities that process, dispose or store radioactive wastes, fissionable materials, or tritium, or conduct separations operations, or conduct irradiated material inspections, fuel fabrication, decontamination, or recovery operations.

Reference G.2 describes hazard management as a necessary part of long-term stewardship and identifies two primary features, engineered and institutional controls. Ref. G.2 states that engineered controls include actions to stabilize and/or physically contain or isolate the waste or its contaminants so they do not reach man. Institutional controls are legal or other non-engineering measures intended to affect human activities in such a way as to prevent receptors from contacting residual hazards in the waste. The FG considers a third important feature of the ORWBG, its landscape features (clay content of the soil, groundwater flow rate, and distance from streams) to be important parameter. Although not identified as a factor considered in institutional controls, these natural features result in short-lived radionuclides decaying in situ and reduce the release rate of other radionuclides to levels that present no threat to future generations.

SRS, EPA and SCDHEC have agreed to implement a process to list and ensure all controls identified in the ROD for a closed waste unit are properly managed. This requires a Land Use Control Assurance Plan (LUCAP) (Ref. G.3) be prepared for SRS to contain procedures for all land use controls (LUC) to ensure that they remain effective over the long-term. The Manager of DOE-SR has the responsibility to certify that all closed units are in compliance every 5 years and notify EPA and SCDHEC of this compliance. The LUC's normally describe the engineered controls and both active and passive institutional controls (IC). Active IC may be controlled access, maintenance or remedial action, controlling or cleaning up releases from the site, and environmental monitoring. Passive IC may include fencing and permanent markers to convey information on the restriction, public records and archives (including easement, deed notification, deed restriction, lease requirement, covenant, etc.), or Government ownership of the land and resources.

The FG assumes that active control would prevent the public from siting homes or businesses on the surface of the ORWBG or from digging into the area between the ORWBG and Fourmile Branch for 150 to 300 years beyond cessation of SRS operations. After 2175 to 2325 active control closes but passive IC remains. As required by the LUCAP process, deed restrictions and marking, fencing, etc will warn future people about the hazards that exist below the ground surface.

After much discussion by the FG on how successful passive institutional controls might be, the FG concluded that an intruder analyses should be used to identify the risk to the intruder. This analysis could be similar to those used in establishing limits for new waste disposal facilities (PAs) and evaluated in the CMS/FS (Ref. G.4). In these intruder analyses, passive IC is assumed to have failed temporarily. The analysis assumes that the intruder will be exposed to the consequence of this intrusion for up to one year before the system recognizes and corrects the breach.

G.3 Technical Approach for Intruder Analysis

Intruder Analysis for Performance Assessments

WSRC reviewed the technical approach used for intruder analysis in SRS Performance Assessments (PA) for the FG on August 2, 2000. A PA for intruders is required for new waste disposal facilities by DOE Order 435.1. The Order requires that an inadvertent intruder not be exposed to more than 100 mrem/yr from all pathways or more than 25 mrem/yr from water or will not exceed 500 mrem from a single exposure event. (10 CFR 61 [Ref G.5] has similar requirements for new commercial LLW disposal facilities.) The DOE Order requires the analysis to consider reasonable activities consistent with regional social customs, such as well drilling, excavation and construction practices, and environmental conditions projected for the time that the intrusion is assumed to occur. When unusual waste is contacted the intruder is assumed to take reasonable action. Several intruder scenarios are assumed in the SRS PAs:

- Excavation scenarios for construction of buildings/home basements
- Drilling water wells
- Post-drilling scenario
- Agricultural scenario and
- Residential scenario

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<u>Intruder Analysis for the CMS/FS for the ORWBG</u>

Science Applications International Corporation (SAIC) reviewed the intruder analysis included in the CMS/FS for the FG. The objectives of the intruder analysis in the CMS/FS were to identify if any radiological hot spots required intruder protection and to assess how the various caps that may be placed on the ORWBG might affect the consequence of intrusion. The CMS/FS predated DOE Order 435.1 and so the intruder analysis was developed from 10 CFR 61 rulemaking. There is no regulatory requirement for an intruder analysis at the ORWBG. Four intruder scenarios were used in the CMS/FS analysis. Three of the four were acute exposure scenarios (drilling, construction, and discovery) and the fourth was an agricultural scenario. The intrusion impacts were compared with the 500 mrem acute exposure limit and the 100 mrem/yr chronic limit. The CMS/FS analysis assumed a 10,000-year time horizon. The inventories were decayed and after active institutional control were assumed to be lost, the cap on the ORWBG and the waste was eroded at a rate of 1.4 mm/yr. The analysis assumed active IC was lost immediately in the No-Action Alternative and maintained for 100 years in all other cases. The CMS/FS analyzed 100, 300, 500, 1,000, 3,000, 5,000, and 10,000 year hot spots. The CMS/FS concluded that hot spots that would persist for 100 years did not need intrusion barriers but that areas with long-lived radionuclides, such as C-14 or Pu-239 required intrusion prevention for a long time. The analysis further concluded that cover features delay but seldom eliminate chronic impacts.

WSRC summarized the similarities and differences between the CMS/FS and PA analysis:

- CMS/FS assume 500 mrem acute limit. The PA scenarios use both 100 and 500 mrem limits.
- The CMS/FS drill scenario assumes that when hard materials are encountered, the drill bit is changed and drilling continued. The PA analysis assumes drilling stops when hard material is encountered.
- Excavation of basements is the same in each analysis.
- The CMS/FS assumes, for the agricultural scenario, that the intruder obtains all of his food from the land contaminated by drilling and construction. The PA analysis assumes the intruder obtained 50% of his food from the contaminated land and purchased the remainder.
- The CMS/FS analysis is biased to the hot spots, that is, it assumes a worst condition. The PA assumes average conditions.

<u>Erosion Rate Assumptions</u>

The 1.4 mm/yr. rate of soil erosion (Ref. G.6), assumed in both the PA and the CMS/FS is typical of plowed fields in the area of SRS. If this rate were constant the 4 feet of engineered permeability native soil cover plus the 4 feet of dirt covering the waste would be eroded away in about 1,750 years. At that time the remaining waste would have no soil cover and the remaining radionuclides would erode out and wash to the surrounding creeks via surface runoff at a much higher rate that is analyzed in Appendices C, D, and E for radionuclide transport via groundwater.

It is obvious that an erosion rate of 1.4 mm/yr is unacceptable. Management of the surface of the ORWBG must slow or prevent erosion. Erosion must be minimized over the long-term, and the surface treatment must not allow deep rooted plants (e.g., pine trees, etc.) to grow on the surface cap, nor allow deep burrowing animals (in this case, ants) to scavenge the waste buried in the trenches and bring the material to the surface.

The FG reviewed one possible treatment that would meet the anti-erosion criteria. Other treatments are possible. This treatment assumed a multi-layer cover installed and planted with a combination of two bamboo species. The bamboo, once established, grows 6 to 8 feet tall and forms a dense top cover shading out the natural succession forests. The bamboo has very shallow roots and will not penetrate the buried waste. It was stated that the soil erosion for this type of cover would be similar to that of a natural succession forest with 0.007-mm/yr erosion (Ref. G.6). This erosion rate would require several ten thousands of years to erode away the cover soil.

The FG recommends that DOE cover the ORWBG with an erosion control cover that prohibits deep-rooted plants and slows the erosion rate. The FG sees no justification for immediate capping of the ORWBG but the schedule must be adequate to ensure the cover performs the intended function before active institutional control is lost **(Recommendation G-3).** In fact the FG thinks some delay in installing the cover would be desirable because delay would allow technology to develop an improved cover while the present cover is maintained by active IC. As indicated in Appendix H, the ORWBG is not unique in this condition. Other DOE and DoD sites have long-lived contaminants that must be similarly protected.

G.4 Sensitive Analysis of Hot Spot Areas

The FG examined the radionuclide and chemical content of various areas of the ORWBG to see what the major long-term inventories were. The sensitivity analysis used the data provided in the CMS/FS for the curies of activity buried and the decay of that inventory. The analysis concluded that most of the short-lived radionuclides would decay in a couple of hundred years, leaving three hot spots containing plutonium, three containing carbon-14, and one containing mercury. These long-term hot spots will require long-term management.

The analysis was a fairly simple one that looked at the inventory in the CMS/FS hot spots and considered more than 200 curies to be significant. (Table G-1) The CMS/FS identified 21 areas; the FG assumption of 200 curies as significant reduced the 21 to 12 100 years after burial, 6 at 300 years, and 5 at 500 years. Stable mercury was also considered a hot spot and would remain one throughout the period of analysis.

Table G-1
ORWBG Hot Spot Inventories, Values in Curies [a,b]

	Curies at				
	Burial	**50 Years**	**100 Years**	**300 Years**	**500 Years**
Hot Spot					
HS-100-1	231,000	15,100	1,800	300	137
HS-100-2	32,300	1,940	117	0	0
HS-100-3	57,500	3.430	210	0	0
HS-100-4	570	104	77	73	71
HS-100-5	59,200	3,540	210	1	1
HS-100-6	157,000	17,000	6,300	1,800	1,000
HS-100-7	181,000	11,500	920	4	2
HS-100-8	58,000	3,470	210	0	0
HS-100-9	1,780	554	172	2	0
HS-100-10	2,440	297	112	20	4
HS-100-11	53,800	3,220	193	0	0
HS-100-12	153	105	72	18	8
HS-100-13	5,970	4,060	2,800	900	500
HS-100-14	46,800	2,800	169	0	0
HS-100-15	41,400	2,510	174	5	1
HS-100-16	38,500	264	76	42	40
HS-100-17	275,000	16,500	1000	1	0
HS-100-18	14,000	3,860	1,100	700	600
HS-100-19	644,000	19,000	4,900	2,000	1,800
HS-100-20	121,000	3,650	700	400	400
HS-100-21	154,000	4,530	500	100	100
HS-Hg-1	5,326 Pounds of Mercury				

[a] Inventories from Tables 2-9 through 2-50 of CMS/FS
[b] Inventories in 2000 were not given in the hot spot tables.

Table G-2 gives the principal radionuclides in the decayed inventories for 100, 300 and 500 years hence. The 100-year period includes some of the short-lived radionuclides and all of the longer-lived radionuclides. By 300 years, all of the short-lived radionuclides have decayed away, leaving only the longer-lived radionuclides. At 300 and 500 years, the only radionuclides are plutonium-239 and -238, and carbon-14. The significance of this is that there are three persistent materials (carbon-14, plutonium, and mercury), each with different environmental characteristics, that must be managed.

Table G.2
Radionuclide Content of Hot Spots [a,b]
(Percent of total)

Hot Spots	100 Years	300 Years	500 Years
HS-100-1	40 Pu-238; 6 Pu-239; 47 Tritium	57 Pu-238; 41 Pu-239	21 Pu-238; 76 Pu-239
HS-100-2			
HS-100-3	100 Tritium		
HS-100-4			
HS-100-5	99 Tritium		
HS-100-6	5 C-14; 79 Pu-238; 7 Pu-239; 8 Tritium	18 C-14; 57 Pu-238; 25 Pu-239	32 C-14; 21 Pu-238; 46 Pu-239
HS-100-7	16 Cs-137; 14 Sr-90; 70 Tritium		
HS-100-8	100 Tritium		
HS-100-9			
HS-100-10			
HS-100-11			
HS-100-12			
HS-100-13	86 Pu-238; 13 Pu-239	57 Pu-238; 43 Pu-239	21 Pu-238; 78 Pu-239
HS-100-14			
HS-100-15			
HS-100-16			
HS-100-17	2 Cs-137; 1.8 Sr-90; 96 T		
HS-100-18	60 C-14; 15 Cs-137; 14 Pu-238; 16 Sr-90; 12 Tritium	99 C-14; 1 Pu-238	100 C-14
HS-100-19	38 C-14; 19 Cs-137, 14 Pu-238; 16 Sr-90; 12 Tritium	91 C-14; 6.8 Pu-238; 1.5 Pu-239	97 C-14; 2 Pu-239
HS-100-20	62 C-14; 7 Cs-137; 6 Sr-90; 24 Tritium	100 C-14	100 C-14
HS-100-21	18 C-14; 19 Cs-137; 5 Pu-238; 41 Tritium		

[a] Where no values are given in table, total curies was less than 200. Where values don't total 100% other nuclides are responsible for the remaining activity.

[b] All calculations consider only decay and no transport with the groundwater from the emplacement site. Tritium is expected to be transported by water. C-14 transport by water is less; see Appendix D.

The average plutonium concentration in the three plutonium hot spots range between 15 and 141 ηCi/g soil at 300 years and between 8 and 77 ηCi/g soil at 500 years. The decrease is a result of the decay of the short-lived Pu-238. These values assume the plutonium is averaged over the area of the hot spot as given in the CMS/FS and assumes the waste is 6 feet deep. This can be compared with the <100 ηCi/g soil that defines the TRU waste lower limit.

The three C-14 hot spots contain between 2,800 to 3,100 curies of C-14 after 300 years. This inventory will be reduced somewhat by ground water transport as shown in Appendix D. The groundwater is expected to transport only a small portion of the total C-14 inventory by 500 years but all of it by 3,000 years. After about 3,000 years the C-14 hot spots will no longer exist. This assumption makes the same assumption that the

CMS/FS makes; that is all of the C-14 is available for transport. This is conservative for water transport but non-conservative for intruder considerations. Packaging of the C-14 or its adherence to resins will probably delay release and lengthen the actual time it remains at the hot spots. In this Appendix, the assumption is made that the C-14 does not move away from the burial location by groundwater transport. This of course is a conservative, yet unrealistic, assumption.

Although mercury is not shown in Table G-2, Attachment D shows that mercury is expected to be transported to Fourmile Branch starting in about 1,000 years and be gone from the ORWBG by 3,500 years. This makes the same assumption that the CMS/FS makes; that all of the mercury is available for transport. It is recognized that mercury can, and probably does, exist in different chemical compounds with markedly different groundwater transport parameters. This is a conservative assumption for water transport but non-conservative for intruder considerations. Packaging of the mercury for disposal will delay release and increase the transport time. In this Appendix, the assumption is made that the mercury does not move away from the burial location. This is a conservative, yet unrealistic, assumption.

G.5 CMS/FS Dose Consequence

As discussed in Section G.2, the differences between the PA and CMF/FS intruder analyses were fairly small. In view of these minor differences, the FG decided to use the results obtained in the CMS/FS for this analysis. Appendix B of the CMS/FS provides the information used in this appendix.

The CMS/FS intruder analytical results are contained on pages 41 through 82 of Reference G.4. The CMS/FS provided intruder dose commitment information for the ORWBG in its present state (that is with an average of 4 feet of natural dirt placed over the trenches as waste was buried and the additional 4 feet of low permeability soil placed over most of the ORWBG in 1998 as an interim measure) and three engineered caps with and without a synthetic cover. For each of these eight conditions four intruder scenarios were calculated, each with several dose pathways. An example of this analyses shown in Table G-3 for HS-100-6, one of the Pu-239 500-year hot spots.

Table G-3
Intruder Consequence for HS-100-6 at 500 Years
(from page 51 of Appendix B of the CMS/FS)

Scenario (Described on Pages B-2 and 3 of CMS/FS)	**50-year Committed Dose from Intrusion, mrem**
Drilling[1]	0
Construction[2] (Air)	830
Construction (Direct Gamma)	1
Construction (Total)	830
Discovery[3] (Air)	10
Discovery (Direct Gamma)	0.01
Discovery (Total)	10
Agricultural[4] (Air)	350
Agricultural (Direct Gamma)	1
Agricultural (Food)	86
Agricultural (Total)	440

1. A well driller drills into the waste to establish a water well for a homestead.
2. Defines the consequence of construction of a house with a basement on the disposal site. Construction crew doesn't recognize the waste and considers it to be normal construction debris.
3. The discovery scenario is the same as above but the construction crew recognizes the waste and ceases construction immediately.
4. This scenario involves an intruder who occupies the house constructed in 2 above and establishes a garden in the contaminated soil and grows all of his food. This is a chronic scenario where the other three are acute scenarios.

Table G-4 illustrates the impact of time on two hot spots. Time is a consideration because short half-lived radionuclides will decay during the first 100 years and the surface of the ORWBG could erode (see Section G.3). HS-100-6 has significant Pu-239 (half-life of 24,390 years) and HS-100-7 contains only short-lived radionuclides.

Table G-4
Intruder Consequence for HS-100-6 and HS-100-7
For Agricultural Scenario, 50-year Committed Dose in mrem

	50-year Committed Dose (mrem)	
Time, Yrs.	**HS-100-6**	**HS-100-7**
0	840	3,700
100	800	430
300	520	7
500	440	2
1,000	660	2
3,000	1,200	3
5,000	1,200	3
10,000	1,100	3

As can be seen from Table G-3, the construction and agricultural scenarios provide the principal consequences to an inadvertent intruder. The construction scenario becomes less important as time progresses, apparently due to decay of the short-lived radionuclides that have a significant gamma activity. Table G-5 provides a ratio of the acute construction consequence to the chronic consequence for the agricultural scenario for the same two hot spots as in Table G-4. As can be seen, the agricultural (chronic) scenario becomes the predominant scenario after the short-lived radionuclides decay.

Table G-5
Ratio of Construction to Agriculture Scenario Consequences

Time, Yrs.	HS-100-6	HS-100-7
0	13.8	0.8
100	6.9	0.6
300	3.1	0.5
500	1.9	0.6
1,000	1	0.4
3,000	0.5	0.2
5,000	0.5	0.2
10,000	0.5	0.2

Given the FG assumption, identified in G.2, that active IC will prevent the public from locating on the ORWBG or digging the area between the ORWBG and Fourmile Branch for 150 to 300 years, the FG decided to evaluate the agricultural consequences that might be encountered after cessation of active ICs. Table G-6 lists the total agricultural consequence (mrem/year) for all of the hot spots after remaining 300 years. These results were obtained from pages 41 through 82 of Appendix B of the CMS/FS. (The name of the hot spots areas were shortened in this section from HS-100-1 to HS-1.) HS-1, -6, and -12 are the plutonium hot spots identified in the sensitivity analysis (Table G-2). HS-18, -19, and -20 are the C-14 hot spots, also identified in Table G-2. The radionuclide inventory in HS-12 and -16 do not seem to substantiate the doses given in the table. (The FG did not attempt to substantiate the doses given for these two hot spots, but only noted the anomaly.) Health risks were estimated using the maximum 50-year committed dose provided in the CMS/FS, 14,000 mrem from HS-16, though the FG believes the data is excessively conservative as stated earlier in this appendix.

From the doses from the Pu-239 and C-14 hot spots (Table G-6) and the curies at those hot spots (Table G-1), it is apparent that a curie of Pu-239 impacts about a thousand times the dose commitment of a curie of C-14. This is substantiated by examining the CEDE factors for the two radionuclides as given in Tables 3A and 3B from Appendix C of this report.

As can be seen from Table G-6, the maximum 50-year committed dose commitment for a plutonium hotspot is 3,900 mrem or 3.9 rem. This analysis allows the surface of the

ORWBG to erode away at 1.4 mm/yr. If surface management control is implemented, the increases in dose (Table G-5) after 1,000 years will not occur. The FG did not recompute the consequences assuming the slower erosion rate.

If an individual were to dig into the land between the ORWBG and Fourmile Branch and use the contaminated ground water, the dose he could receive would depend upon when

Table G-6
Intruder Dose for Agricultural Scenario,
50-year Committed Dose (mrem)
(Data from Appendix B of the CMS/FS [Ref. G.4])

Hot Spots	Years into the Future						Radionuclide[a]
	300	500	1,000	3,000	5,000	10,000	
HS-1	95	110	190	390	380	340	Pu-239
HS-2	1	0	0	0	0	0	
HS-3	0	0	0	0	0	0	
HS-4	0	0	0	1	1	1	
HS-5	5	7	10	14	14	14	
HS-6	520	440	660	1,200	1,200	1,100	Pu-239
HS-7	7	2	2	3	3	3	
HS-8	0	0	0	0	0	0	
HS-9	92	6	7	9	9	9	
HS-10	580	130	4	1	1	1	
HS-11	0	0	0	0	0	0	
HS-12[b]	0	24	380	1,500	1,400	1,300	
HS-13	2,400	2,000	2,700	3,900	3,700	3,300	Pu-239
HS-14	5	6	8	10	10	9	
HS-15	31	14	8	16	15	13	
HS-16[b]	4,500	6,200	10,000	14,000	11,000	6,000	
HS-17	2	0	0	0	0	0	
HS-18	17	1	1	2	2	2	C-14
HS-19	2,300	3,800	7,400	13,000	10,000	5,500	C-14
HS-20	33	2	2	2	2	2	C-14
HS-21	107	15	4	5	5	5	

[a] Predominant nuclide; however, it is not necessarily the radionuclide contribution the most to the dose.
[b] Radionuclides in these two hot spots do not substantiate the high dose rates given in this table.

the intrusion occurred and where it was located. If an intruder were to drink for a period of one year the contaminated groundwater obtained from the geometric center between the ORWBG fence and the seep line, the 50-year committed dose could be 55 mrem after about 600 years as the peak Np-237 and C-14 groundwater concentrations pass. It would peak again at 2 mrem after about 4,000 years when the peak U-238 and U-235 concentrations passed. The geometric center was selected for this analysis to average the chance of intrusion. (It is recognized that if the intrusion were closer to the ORWBG the peak concentrations and doses would be higher at an earlier time. Conversely, the concentrations and doses would be lower if the intrusion occurred later and nearer the creek.)

References for Appendix G

G.1 "*SRS Long Range Comprehensive Plan"*, US Department of Energy-Savannah River Operations Office, December 2000.

G.2 Draft *"Long Term Stewardship Study"*, U. S. Department of Energy, Office of Environmental Management, Office of Long-Term Stewardship, Draft for Public Comment, October 2000.

G.3 *"Land Use Control Assurance Plan for the Savannah River Site"*, Westinghouse Savannah River Company, Report Number WSRC-RP-98-4125, Revision 1.1, August 99.

G.4 *"Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-G"*, Westinghouse Savannah River Company, Report Number WSRC-RP-98-4012, Rev. O, March 1999.

G.5 Title 10 (Energy) of Code of Federal Register Part 61 *"Licensing Requirements for land Disposal of Radioactive Wastes"*, 10-CFR-61.

G.6 *"Estimated Erosion Rate at the SRP Burial Ground"*, by J. H. Horton and E. L. Wilhite, Savannah River Laboratory, Report DP-1493, April 1978.

Appendix H.

Human Health Effects from Exposure to Radiation and Radioactive Materials

This appendix introduces the concepts of human health effects as a result of exposure to radiation and radioactive materials. Specifically, the appendix explains the nature of radiation, sources of radiation, types of radiation, how radiation interacts with the human body, how radiation dose is calculated, and how risk factors are used to estimate potential health effects that may result from radiation exposure. In addition, the appendix also summarizes dose estimates presented in Sections 5, 6, and 7 of this report (and Appendices E, F, and G) and presents estimates of potential health effects that could result from these doses. Finally, the appendix includes a discussion of conservatism and uncertainties inherent to commonly used radiation risk assessments and sections on radiation risk in perspective and future research.

H.1 Radiation and radioactivity

Radiation is the emission and propagation of energy through space or through a material in the form of waves or bundles of energy called photons, or in the form of high-energy subatomic particles; radiation generally results from atomic or subatomic processes that occur naturally. The most common kind of radiation is *electromagnetic radiation,* which is transmitted as bundles of energy or photons. Electromagnetic radiation is emitted over a range of wavelengths and energies. We are most commonly aware of visible light, which is part of the spectrum of electromagnetic radiation. Radiation of longer wavelengths and lower energy include infrared radiation, which heats material when the material and the radiation interact, and radio waves. Electromagnetic radiation of shorter wavelengths and higher energy (which are more penetrating) include ultraviolet radiation, which causes sunburn; X-rays; and gamma radiation.

Ionizing radiation is radiation that has sufficient energy to displace electrons from atoms or molecules, thus creating (positively or negatively charged particles) ionizing radiation. It can be electromagnetic (for example, X-rays, gamma radiation) or is the form of subatomic particles (for example, alpha and beta radiation). The ions interact with other atoms or molecules because of their charge. In biological systems, this interaction can cause damage in the tissue or organism.

Radioactivity describes the characteristic of an unstable atom to undergo spontaneous transformation (to *disintegrate* or *decay*) with the emission of energy as radiation. Usually the emitted radiation is ionizing radiation. The transformation of an unstable atom (a *radionuclide*) into a different, more stable atom, with less energy, is accompanied by the release of excess energy (as radiation). This is termed *radioactive decay*.

Radioactive decay produces three main types of ionizing radiation—alpha particles, beta particles, and gamma or X-rays—that our senses cannot detect. These types of ionizing radiation have different characteristics and levels of energy and, thus, varying abilities to penetrate biological tissue and interact with atoms in an organism. (This discussion is restricted to humans, but radiation can affect all living things.) Because each type has different characteristics, each requires different amounts of material to stop (shield) the radiation. Alpha particles are the least penetrating and can be stopped by thin layers of material, such as a single sheet of paper. However, when radioactive atoms in the body (called radionuclides) emit alpha particles as they decay much energy is concentrated near those atoms. Shielding against beta particles requires thicker material, such as several reams of paper or several inches of wood or water. Shielding from gamma rays electromagnetic radiation, which is highly penetrating, requires very thick material, such as several inches to several feet of concrete or lead. The energy of gamma rays is dispersed throughout the body and contrasted to the local energy deposited in a small area by an alpha particle. In fact, some gamma radiation passes through biological tissue without interacting with it.

In a nuclear reactor, heavy atoms such as uranium and plutonium can undergo another process, called *fission*, after the absorption of a subatomic particle (usually a neutron). In fission, a heavy atom splits into two lighter atoms and releases energy in the form of radiation and the kinetic energy of the two new lighter atoms. The new lighter atoms are called fission products. The fission products are usually unstable and undergo radioactive decay to reach a more stable state.

Some of the heavy atoms might not fission after absorbing a subatomic particle. Rather, a new nucleus is formed that tends to be unstable (like fission products) and undergo radioactive decay. These newly formed nuclei are called *transuranic* radionuclides or *transuranics*.

The radioactive decay of fission products and unstable heavy atoms are the sources of the radiation from radioactive waste that makes this material hazardous.

H.2 Exposure to Radiation and Radiation Dose

Radiation that originates outside an individual's body is called *external* or *direct radiation*. Such radiation can come from an X-ray machine or from *radioactive materials* (materials or substances that contain radionuclides), such as radioactive waste or radionuclides in soil. *Internal radiation* originates inside a person's body following intake of radioactive material or radionuclides through ingestion (eating) or inhalation (breathing). Once in the body, its chemical behavior and how it is metabolized determine the fate of a radioactive material. If the material is soluble, it might be dissolved in body fluids and transported to and deposited in various body organs; if it is insoluble, it might move rapidly through the gastrointestinal tract or be deposited in the lungs.

Exposure to ionizing radiation is expressed in terms of *absorbed dose,* which is the amount of energy imparted to matter per unit mass. Often simply called *dose,* it is a fundamental concept in measuring and quantifying the effects of exposure to radiation. The special unit of absorbed dose is the *rad.* The different types of radiation have different effects on the cells of biological systems. *Dose equivalent* is a concept that considers (1) the absorbed dose and (2) the relative effectiveness of the type of ionizing radiation in damaging biological systems, using a radiation-specific quality factor. The unit of dose equivalent is the *rem.* In quantifying the effects of radiation on humans, other concepts are also used. The concept of *effective dose equivalent* is used to quantify effects of radionuclides in the body. It involves estimating the susceptibility of the different tissues in the body to radiation to produce a tissue-specific weighting factor. The weighting factor (sometimes referred to as a *cancer fatality coefficient*) is based on the susceptibility of that tissue to cancer from radiation exposure. The sum of the products of each affected tissue's estimated dose equivalent multiplied by its specific weighting factor is the *effective dose equivalent.* The potential effects of radionuclides are usually considered for more than 50 years—the commitment period—to account for radionuclides that have long half-lives and a long residence time in the body. The result is called the *committed effective dose equivalent.* The unit of effective dose equivalent is also the *rem. Total effective dose equivalent* is the sum of the committed effective dose equivalent from radionuclides in the body plus the dose equivalent from radiation sources external to the body (also in rem). All estimates of dose presented in this report, unless specifically noted as something else, are total effective dose equivalents, which are quantified in terms of rem or millirem (one one-thousandth of a rem). More detailed information on the concepts of radiation dose and dose equivalent are presented in publications of the National Council on Radiation Protection and Measurements (NCRP) (Ref. H.18) and the International Commission on Radiological Protection (ICRP) (Ref. H.11).

The factors used to convert estimates of radionuclide intake (by inhalation or ingestion) to dose, are called *dose conversion factors*. The NCRP and Federal agencies such as the Environmental Protection Agency (EPA) publishes these factors (Ref. H.20; Ref. H.5; Ref. H.6). They are based on original recommendations of the ICRP (Ref. H.9).

The radiation dose to an individual or to a group of people can be expressed as the total dose received or as a dose rate per unit time (usually an hour or a year).

Collective dose is the total dose to an exposed population. *Person-rem* is the unit of collective dose. Collective dose is calculated by summing the individual dose to each member of a population. For example, if 100 workers each received 0.1 rem, then the collective dose would be 10 person-rem (100 × 0.1 rem).

Exposures to radiation or radionuclides are often characterized as being acute or chronic. Acute exposures occur over a short period of time, typically 24 hours or less. Chronic exposures occur over longer times (months to years), and are usually assumed to be continuous over a time period, although the dose rate may vary. For a given dose of radiation, chronic radiation exposure is usually less harmful than acute exposure because the dose rate (dose per unit time, such as rem per hour) is lower, providing more opportunity for the body to repair damaged cells.

H.3 Background Radiation from Natural Sources

Nationwide, on average, members of the public are exposed to approximately 360 millirem per year from natural and manmade sources (Ref. H.4). Figure F-1 shows the relative contributions by radiation sources to people living in the United States (Ref. H.4). The estimated average annual dose rate from natural sources is about 300 millirem per year and accounts for about 80 percent of the annual dose received by an average member of the U.S. public. The largest natural sources are radon-222 and its radioactive decay products in homes and buildings, which contribute about 200 millirem per year. Additional natural sources include radioactive material in the Earth (primarily the uranium and thorium decay series, and potassium-40) and cosmic rays from space filtered through the atmosphere. With respect to exposures resulting from human activities,

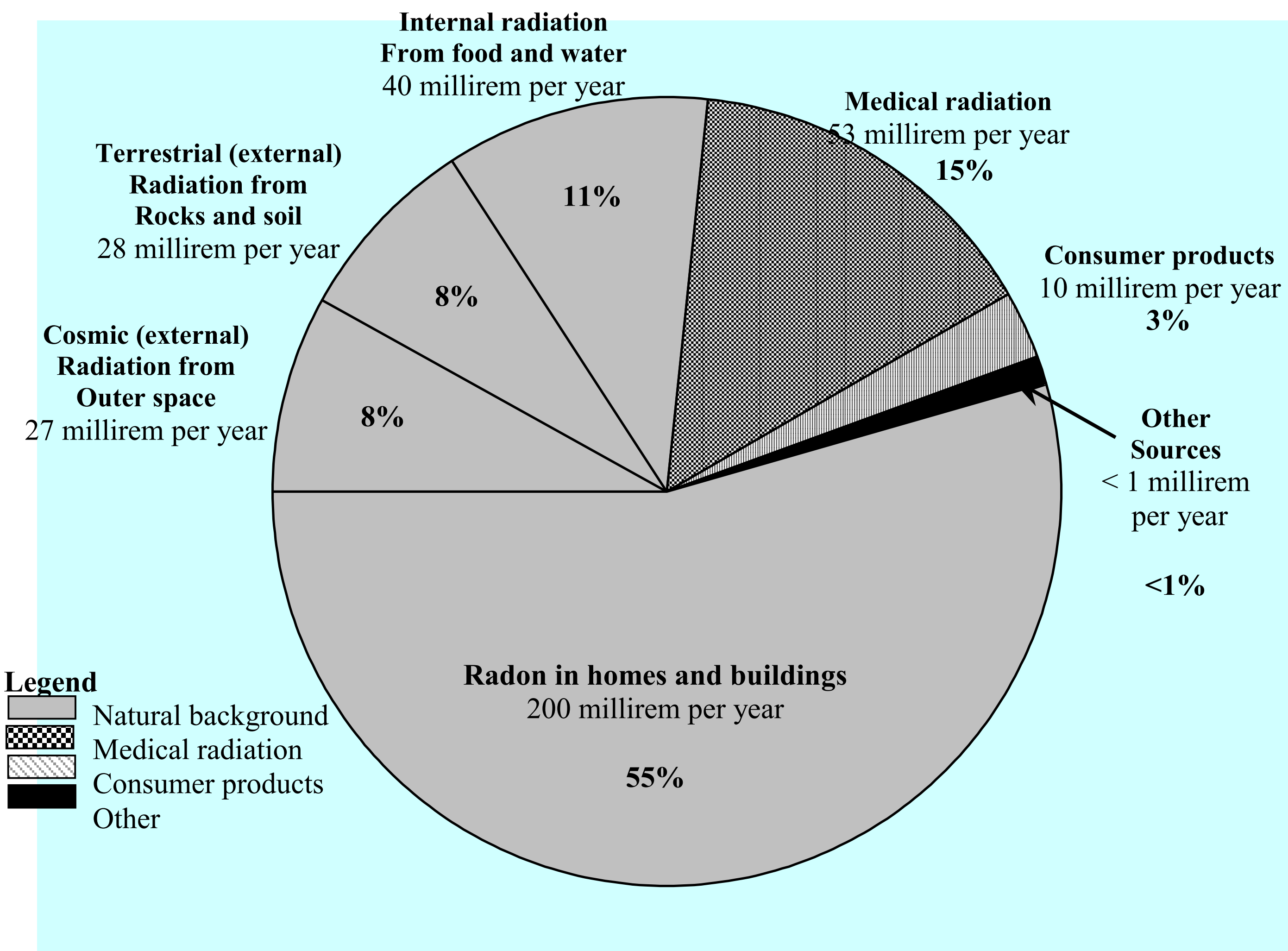

Figure H-1.
Sources of radiation exposure.

medical exposure accounts for 15 percent of the annual dose, and the combined doses from weapons testing fallout, consumer and industrial products, and air travel (cosmic radiation) account for the remaining 3 percent of the total annual dose. Nuclear fuel cycle facilities contribute less than 0.1 percent (0.005 millirem per year per person) of the total dose (Ref. H.4).

H.4 Health Effects from Radiation Exposure

H.4.1 Acute Exposure to High Doses

Exposures to high levels of radiation at high dose rates over a short time (less than a few days) can result in acute radiation effects. For high external doses, the biological effects depend more on absorbed dose received rather than dose equivalent (Ref. H.27). Therefore, it is typical to report high doses from acute external exposures in terms of rads instead of rem. A rad represents the same amount of energy as a rem but because it is deposited in a shorter period of time it has a different biological effectiveness.

From external exposures, minor changes in blood characteristics might be noted at doses in the range of 25 to 50 rad. The symptoms of radiation sickness begin to appear following acute exposures of about 100 rad and can include anorexia, nausea, and vomiting. More severe symptoms occur at higher doses and can include death at doses higher than 200 to 300 rad of total body irradiation, depending on the level of medical treatment received. Information on the effects of acute exposures on humans was obtained from studies of the survivors of the Hiroshima and Nagasaki bombings and from studies of acute accidental exposures (Ref. H.12).

Other effects may follow acute exposures to specific portions of the body. Temporary sterility in men and women has been observed following irradiation of the gonads to doses in the tens to hundreds of rads. Erythema (reddening of the skin) can occur when the skin is exposed to high doses of low energy radiation (Ref. H.2). In patients treated with external radiation beams for cancer therapy, pulmonary fibrosis, or other lung disorders, erythema can occur.

For internal exposures, doses are calculated for a 50-year period (50-year *committed* dose) following intake. Therefore, although the intake may be acute, the dose itself is delivered chronically over a period of 50 years. Thus, higher internal doses are required to achieve the same bioeffects as that due to acute external doses. For example, for radionuclides that have long half-lives and long residence times in the body, such as plutonium 239, an acute intake of only about one fiftieth of the calculated 50-year committed dose would be received each year but the exposure would continue essentially at the same rate for the next 50 years. In fact, based on lung burdens derived by the ICRP in its Publication 31, *Biological Effects of Inhaled Radionuclides*, an internal *committed* dose of 130,000 to 4.3 million rem would be required to cause death shortly after intake from inhalation of plutonium-239 (Ref. H.29). This is an extremely high dose that could not be readily achieved under normal conditions and would be possible only in severe accident circumstances. Medical treatments have been developed that reduce the internal dose by removing the radioactive material from the body, either through enhancing excretion or through surgery. Thus, the probability of an individual with a high intake of radionuclides dying from internal exposures is extremely small.

On the other hand, radionuclides that have relatively short residence times in the body and sufficiently long half-lives, such as tritium, will deliver essentially the entire calculated 50-year committed dose in the year the intake occurred.

H.4.2 Acute or Chronic Exposure to Low Doses

Most of the calculated radiation doses in this report are from chronic exposures, where a person is exposed almost continuously to very low doses of radiation. Although other effects are possible, cancer is the principal potential risk to humans from exposure to low doses of radiation. However, cancer induction is a statistical process; it does not necessarily occur following exposure to radiation, and it can occur for reasons other than radiation exposure.

It is generally recognized that there are other health effects besides fatal cancers that could result from exposure to radiation. Examples are nonspecific life-shortening and some genetic effects. The ICRP suggested the use of detriment weighting factors that take into consideration the curability rate of nonfatal cancers and the reduced quality of life associated with nonfatal cancer and hereditary effects (Ref. H.11). However, both of these life-detriment factors, when taken together, are less than half of the fatal cancer risk. In addition, the National Research Council Committee on the Biological Effects of Ionizing Radiation stated in its BEIR III Report that cancer induction is considered to be the most important effect (Ref. H.22). Therefore, while it is recognized that other effects may occur, the primary health effect is a cancer fatality. In this report effects are calculated on this basis.

Because of the statistical nature of cancer induction, there are no data that show a clear link between low levels of radiation dose and cancer. Most of the data on radiation induction of cancer comes from studying relatively small numbers of people who have received acute exposures to higher doses of radiation (more than 10,000 mrem), such as the atomic bomb survivors. Interpreting this risk in situations where the doses are low requires making an assumption of how the probability of health effects changes with dose. This concept is illustrated in Figure F-2, where a hypothetical plot is drawn to show observed cancer incidence at high doses. As shown in the figure, there is more than one line or curve that could be used to fit the data at higher doses and then predict the effects at the lower doses. However, without a statistically significant number of observed effects in the low dose region of interest, radiation protection organizations such as the International Commission on Radiological Protection have recommended risk factors for the general public (Ref. H.17; Ref. H.11) that have assumed a linear-no-threshold (LNT) hypothesis. This hypothesis is considered conservative in that it assumes that all radiation exposure, no matter how small, involves some risk and that the risk increases directly with dose (see Section H.6 below for more details related to conservatisms related to the LNT hypothesis).

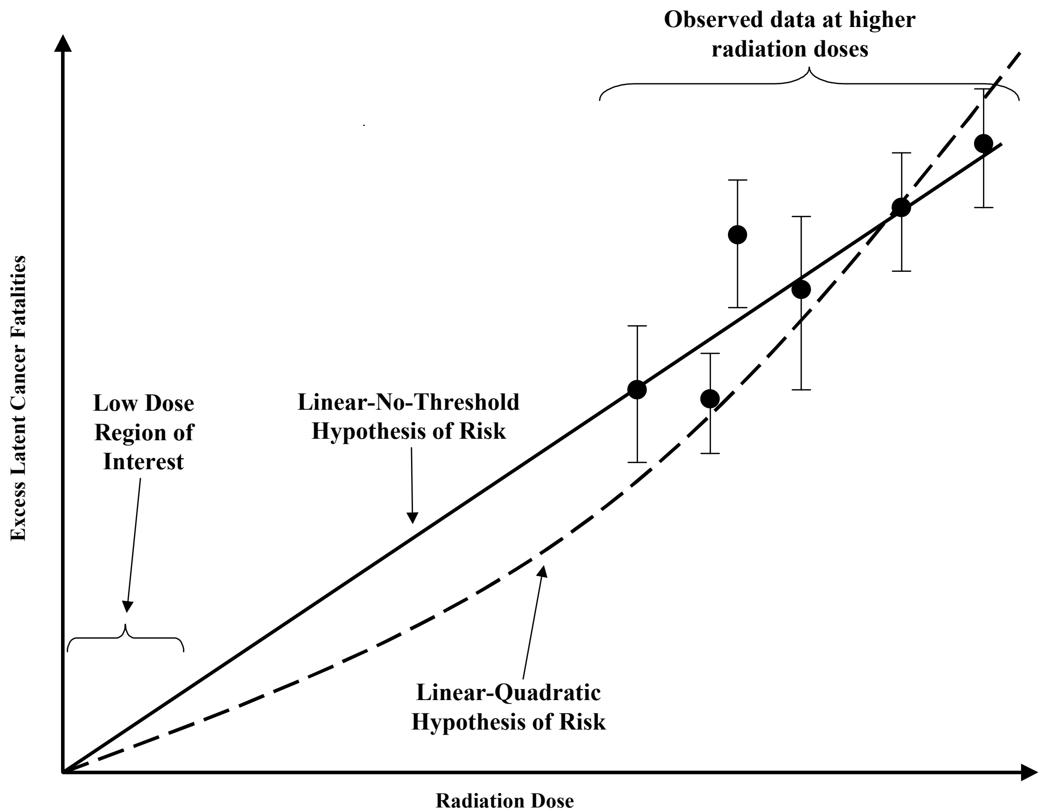

Figure H-2.
Hypothetical plot showing possible projections of radiation risks at low doses. The available data are for high-dose exposures, and the radiation protection organizations have assumed a linear-no-threshold fit to the data for conservatism (Ref. H.27).

This report expresses radiological health impacts as the incremental changes in the number of expected fatal cancers (termed "latent cancer fatalities") for populations and as the incremental increase in lifetime probability of contracting a fatal cancer for an individual. Risk factors are used to calculate these health effects. Because of the uncertainties in the low-dose region, the risk factors give a general indication of the possible health impacts (i.e., potential number of cancers) but should not be interpreted as the exact number of cancers or which individuals would contract a cancer.

The potential impact estimates are based on the dose received and on dose-to-health-effect conversion factors recommended by the International Commission on Radiological Protection (ICRP) (Ref. H.11). The Commission estimated that, for the general population, a collective dose of 1 person-rem could yield 0.0005 excess latent cancer fatality in the exposed population. For radiation workers, a collective dose of 1 person-rem could yield an estimated 0.0004 excess latent cancer fatality in the exposed population. Because young children are more sensitive to radiation and because children make up a large part of the general population, this causes the risk factor for the general population to be greater than that for workers. The radiation worker population includes only people older than 18. The National Council on Radiation Protection and Measurements in 1993 (Ref. H.17) adopted these risk coefficients.

These concepts can be used to estimate the effects of exposing a population to radiation. For example, if 100,000 people were each exposed only to background radiation (300 mrem per year), 15 latent cancer fatalities could occur as a result of 1 year of exposure (100,000 persons multiplied by 300 millirem per year multiplied by 0.0005 latent cancer fatality per person-rem equals 15 latent cancer fatalities per year).

Calculations of the number of latent cancer fatalities associated with radiation exposure do not normally yield whole numbers and, especially in environmental applications, can yield numbers less than 1.0. For example, if 100,000 people were each exposed to a total dose of only 1 millirem (0.001 rem), the population dose would be 100 person-rem, and the corresponding estimated number of latent cancer fatalities would be 0.05 (100,000 persons multiplied by 0.001 rem multiplied by 0.0005 latent cancer fatality per person-rem equals 0.05 latent cancer fatality).

The average number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people is 0.05. In most groups, nobody (zero people) would incur a latent cancer fatality from the 1-millirem dose each member would have received. In a small fraction of the groups, 1 latent fatal cancer would result; in exceptionally few groups, 2 or more latent fatal cancers would occur. The average number of deaths over all the groups would be 0.05 latent fatal cancer (just as the average of 0, 0, 0, and 1 divided by 4 is 0.25). The most likely outcome is no latent cancer fatalities in these different groups.

The same concepts apply to estimating the effects of radiation exposure on a single individual. Consider the effects, for example, of exposure to background radiation over a lifetime. The "number of latent cancer fatalities" corresponding to a single individual's exposure to 300 millirem a year over a (presumed) 70-year lifetime is:

Latent cancer fatality =1 person × 300 mrem per year × 70 years
× 0.0005 latent cancer fatality per person-rem
= 0.011 latent cancer fatality.

Again, this should be interpreted in a statistical sense; that is, the estimated effect of background radiation exposure on the exposed individual would produce a 1.1-percent chance that the individual would incur a latent fatal cancer.

H.5 Dose and Potential Health Effects

Sections 5, 6, and 7 (and Appendices E, F, and G) of this report have described various scenarios and exposure pathways that could result in radiation dose to workers and offsite individuals and populations from radioactive materials disposed of in the ORWBG. Health effects, namely the incremental risk of contracting a fatal cancer, can be estimated with application of the risk factors (discussed in Section H.6 below) for members of the public. Table H-1 below presents a summary of these doses and the estimated health impacts that could result.

Table H-1.
Annual dose and potential health impacts to the maximally exposed individuals (MEIs) from radioactive materials in the ORWBG.

Exposure scenario	Annual Dose (mrem/year)	Annual Risk of fatal cancer	Lifetime Risk of fatal cancer
Groundwater/Surface water contamination			
At Road A MEI (year 2000)	3.5 (from Table 5-4)	1.8×10^{-6} [c]	1.2×10^{-4} [e]
MEI (year 2800)	0.77 (from Table 5-4)	3.9×10^{-7} [c]	2.7×10^{-5} [e]
At Port Wentworth MEI (year 2000)	0.009 (from Table 5-4)	4.5×10^{-9} [c]	3.1×10^{-7} [e]
MEI (year 2800)	0.002 (from Table 5-4)	1.0×10^{-9} [c]	7.0×10^{-8} [e]
Surface Occupation			
Resident MEI (w/o erosion control or IC)	16 [a]	8.1×10^{-6} [d]	2.8×10^{-4} [f]
Intruder MEI (w/o erosion control or IC)	280 [b]	1.4×10^{-4} [d]	3.5×10^{-3} [f]

a. 50-year committed dose (Section 6.3) of 810 mrem (930 – 120) converted to an annual dose by division by 50.
b. 50-year committed dose (from Table 7-1) of 14,000 mrem converted to an annual dose by division by 50.
c. Methodology for determining the annual risk in mrem/year is determined by multiplying dose rate times (0.0005 divided by 1000) as described in Section H.4.
d. Risk based on the assumption that the acute intake of radionuclides with long effective half-lives will result in the annual dose (see Section H.4.1 above).
e. Lifetime risk assumes a lifetime of 70 years; thus lifetime risk equals annual risk times 70.
f. Risk assumes half of the 50-year committed dose for radionuclides with long effective half-lives will be received prior to death as described by NCRP beginning on page 25 (Ref. H.18).

Examination of the calculated doses and risk estimates (Table H-1) reveal several important estimates. First, the dose calculated for the hypothetical maximally exposed offsite individual (3.5 mrem per year from tritium in the year 2000) is currently below the EPA drinking water standard (4 mrem per year for man-made beta- and photon-emitting radionuclides) codified at 40 CFR Part 191.26. Further, the time-dependent analysis summarized in Section 5 of this report suggests that this dose will remain below the current level for the entire 10,000 year analysis period. In addition, the estimated incremental lifetime risk of this maximally-exposed individual contracting a fatal cancer is essentially that which the National Academies of Science and EPA suggest is adequate for the protection of human health (Ref. H.25; Ref. H.8) at a risk that EPA considers an "acceptable exposure level" under CERCLA regulations (40 CFR Part 300.430(e)(2)(I)(A)(2)). Therefore, because the current level of exposure and lifetime risk estimates for an individual drinking water at Road A on the SRS are such that adverse health impacts would be highly unlikely, the FG believes that additional remedial actions to reduce tritium concentrations are not justified. Actual water use at Port Wentworth (maximum concentration) is a small fraction of the 4 mrem drinking water standards ensuring the public is adequately protected.

Assuming that the lifetime risk of contracting a fatal cancer is about 24 percent in the U.S. population (see Section H.6 below for details), the incremental risk to the maximally exposed onsite resident without erosion controls or institutional controls (780 millirem per year) would be estimated to increase his lifetime risk of contracting a fatal cancer from all causes from 24 to 27 percent or about 11 percent. This level of risk is less than that represented by the choice to drive an automobile or, in some cases, the choice of occupation (see Table H-2). Because these levels of incremental risks are, with few exceptions, tolerated by the public, and the fact that the incremental risks to hypothetically exposed onsite residents shown in Table H-1 would occur in only a small group of individuals, the FG can find no justification for expenditure of additional resources to further reduce the risk.

H.6 Perspectives on Risk

While the risk factors cited above are useful for calculations, they must be compared to other risks to be meaningful. For example, according to statistics published by the Centers for Disease Control, in 1995 the national average lifetime risk of contracting a fatal cancer from all causes was 24 percent (Ref. H.13). This means that as of 1995, an individual had almost a 1 in 4 chance of death due to cancer. When this death risk is compared to the additional risk due to an additional 1,000 millirem of radiation, then the individual's overall lifetime risk, using the ICRP risk factors described in Section H.4, could be calculated to have increased by 0.2 percent (i.e., increased from about 24.00 to 24.05 percent).

Another way to evaluate the long-term risk from exposure to radiation is to compare it to other risks encountered on a daily basis. One method for comparison is the Loss of Life Expectancy (LLE), which is an estimate of the average number of days of life lost for a given risk factor for a population.

Table H-2 gives the LLE values tabulated for a variety of activities and circumstances. As shown in this table, a single exposure to 1,000 mrem could result in shortening an individual's life by a little more than 2 days or about the same risk imposed by contracting influenza that results in death. At the bottom of Table H-2 is the estimate of

LLE for several different radiation exposure scenarios, including those calculated for the ORWBG.

Table H-2.
Loss of Life Expectancy (days) for causes of death for average citizens of the United States.[a]

Risk Factor	LLE (days)
Disease	
Cardiovascular diseases	2,043
Cancer – all types	1,247
Chronic pulmonary	164
Pneumonia	103
Diabetes	82
Tuberculosis	4.7
Influenza	2.3
Accidents	
Motor Vehicle Accidents	207
Homicide	93
Accidents at Home	74
Accidents at Work (All)	60
Agriculture	320
Construction	227
Services	27
Radiation Exposure	
Acute exposures	
Single acute exposure of 1,000 mrem	2.3[b]
Single acute exposure of 1 mrem	0.002[b]
Chronic lifetime exposures	
Lifetime of continuous exposure (100 mrem/yr)	15[b]
Natural background radiation: 360 mrem/yr	0.6[b]
EPA Drinking water standard: 4 mrem/yr	0.6[b]
Maximum ORWBG drinkin (year 2800)	0.12[b]
Maximum ORWBG resident dose (810[c] millirem)	1.2[b,d]
Maximum ORWBG intruder dose (14,000[c] mrem)	21[b,d]

a. Tabulated by Cohen (Ref. H.28)
b. Adapted from methodology presented by Cohen (Ref. H.28)
c. 50-year committed dose
d. LLE based on half the 50-year committed dose (Ref. H.18)

As discussed in the preceding section, the risk factor (and hence the LLE) for radiation exposure is based on an assumption that all radiation exposure carries some risk, even though that assumption has not been proven and may overestimate the true risk from low-level exposure. However, even with that assumption, the LLE from radiation exposure is tremendously overshadowed by the LLE for other causes of death in the United States.

In 1993, the NCRP stated the following with regard to the public's tolerance for radiation risks (Ref. H.18):

> ". . . everyone is exposed to natural background radiation, and that, annually, is commonly about 1 mSv [100 millirem] (excluding radon) or an assumed annually incurred lifetime risk of mortality of about 10^{-4} to 10^{-5}. The annual total effective dose from natural sources (excluding radon) varies in the United States from about 0.65 mSv [65 millirem] on the Atlantic Seaboard to 1.25 mSv [125 millirem] in Denver Colorado. The average annual effective dose due to radon is about 2 mSv [200 millirem] and variations in it are much greater (Ref. H.14) than the average value of natural background from other sources."

The point of the NCRP's discussion on the variability in background radiation rates is that members of the public do not generally decide on where to live based on ambient background radiation dose rates. In other words, the risk associated with increased radiation exposure is considered too trivial to be of concern even though, as shown above, the variations could be as much as 200 millirem per year or more. The same could be said of a decision to fly, as opposed to driving, to a destination. Measurements have shown that air travel adds, on average, about 0.5 millirem per hour of flight (Ref. H.26) over the exposure one would expect on the ground. Therefore, for a round trip cross-country flight, one could expect about 4 millirem additional dose. However, this level of increased dose rate and resultant dose is usually not considered in the decision of whether to fly or drive. It should be noted that 4 millirem per year is the EPA's maximum concentration level (MCL) for radionuclides in public drinking water systems. This would imply that, for most people, the drinking water MCL represents a risk that most people believe is too small to be an important factor in their decisionmaking process.

In 1995, the National Research Council stated the following:

> "Traditionally, radiation protection guidelines are predicated on a linear dose response, which assumes that the harmful effects of radiation are linearly related to the dose and that there is no threshold dose. Most experts believe this assumption is conservative; that is, it overestimates the effects of ionizing radiation at low doses because it ignores the potentially beneficial effects of the body's repair mechanisms." (Ref. H.24).

Having said this, the Committee continues:

> "In the past, this probable overestimation of the risk was regarded as a good thing consistent with the still widespread philosophy that it is better to be safe than sorry. This philosophy holds true only when unlimited resources are available to protect the public health and the environment. Once resources are acknowledged to be limited, overestimates of a particular risk are ultimately harmful to the public health because funds are diverted from larger risks to protect society from

> smaller risks. This diversion of funds ultimately will result in greater mortality than would have occurred if resources were spent in proportion to the amount of health benefit that would be achieved." (Ref. H.24).

This last paragraph points to the condition that we find ourselves in currently at the Savannah River Site – namely the we have facilities and materials that represent far greater risks to workers and the public than the ORWBG and its contaminants and a limited, finite budget. Therefore, we must spend the available resources wisely and ensure that they are first used to remediate those areas that represent the greatest risk. The FG believes strongly that the actual risks represented by radioactive materials in the ORWBG are trivial and may in fact, given the uncertainties and conservatisms discussed in Section H.7 below, be zero. Thus, the FG believes that remediation activities at the ORWBG should be limited to soil stabilization and long-term institutional control and that the limited resources available for clean up at SRS be used for higher-risk projects, resulting in a greater overall risk reduction and level of safety for workers and the public.

H.7 Uncertainties and Conservatisms in Estimates of Health Effects

H.7.1 Conservatisms and uncertainties in the linear no threshold (LNT) model

One of the most significant conservatisms is that which has been incorporated into the linear-no-threshold (LNT) hypothesis. Summarized below is a discussion of the application of the LNT hypothesis in the development of dose-effect curves and a brief review of what the leading radiation organizations have stated about the concept.

The risk conversion factor of 0.0005 latent cancer fatality per rem (0.00000051 mrem) of dose for the general public that is typically used in estimating health impacts is based on recommendations of the International Commission on Radiological Protection (Ref. H.11) and the National Council on Radiation Protection and Measurements (Ref. H.17). The factor is based on health effects observed in the high dose and high dose rate region (20,000 to 50,000 mrem per year). Health effects were extrapolated to the low-dose region (less than 10,000 mrem per year) using the LNT model. Because the model is assumed to be a linear function and it is also assumed that there is no dose below which effects could not occur, this model allows the calculation of health effects from any amount of radiation, regardless of how small.

Although the LNT model is generally recommended by the International Commission on Radiological Protection and the National Council of Radiation Protection and Measurements, most radiation protection professionals believe this model produces a conservative estimate (that is, an overestimate) of health effects in the low-dose region, which is the exposure region associated with the doses calculated in this report. Below are excerpts from reports published by various scientific advisory groups over the past several decades on the LNT hypothesis.

- Federal Radiation Council

  "If one assumes a direct linear relationship between biological effect and the amount of dose, it then becomes possible to relate very low dose to an assumed biological effect even though it is not detectable. It is generally agreed that the effect that may actually occur will not exceed the amount predicted by this assumption." (Memorandum that transmitted Report No. 1 to the President (Ref. H.3).

- International Commission on Radiological Protection

  "As a linear relationship between dose and effects has been assumed, the present estimates should be regarded only as upper limits." (Ref. H.10).

Later, in ICRP Publication 26 (Ref. H.9), the ICRP stated that:

  "The use of linear extrapolations, from the frequency of effects observed at high doses, may suffice to assess an upper limit of risk, for which the benefits of a practice, or the hazard of an alternative practice -- not involving radiation exposure -- may be compared. However, the more cautious such an assumption of linearity is, the more important it becomes to recognize that it may lead to an overestimate of the radiation risks, which in turn could result in the choice of alternatives that are more hazardous than practices involving radiation exposures. Thus, in the choice of alternative practices, radiation risk estimates should be used only with great caution and with explicit recognition of the possibility that the actual risk at low doses may be lower than that implied by a deliberately cautious assumption of proportionality." (Ref. H.9).

- National Council on Radiation Protection and Measurements

  "Based on the hypothesis that genetic effects and some cancers may result from damage to a single cell, the Council assumes that, *for radiation-protection purposes, the risk of stochastic effects is proportional to dose without threshold, throughout the range of dose and dose rates of importance in routine radiation protection*. … Given the above assumptions, radiation exposure at any selected dose limit will, by definition, have an associated level of risk." (Italics provided in the text as quoted.) (Ref. H.18).

Through these statements, all of these organizations have sought to make it clear that the linear-no-threshold hypothesis incorporates considerable conservatism. In the case of the NCRP, the objective was to emphasize that, whereas the linear hypothesis has been adopted as a conservative practice in the establishment of radiation protection standards, this does not imply that it should be used for purposes of risk assessment, without careful review and evaluation. Such review and evaluation includes an assessment of the associated conservatisms in this approach. (The same point is emphasized by the BEIR V Committee -- see next item.)

- Committee on the Biological Effects of Ionizing Radiation (BEIR V)

  "… epidemiological data cannot rigorously exclude the existence of a threshold in the millisievert dose range. Thus the possibility that there may be no risks from exposures comparable to external natural background radiation [which ranges from about 0.5 to 1.5 mSv (50 to 150 mrem) per year in the U.S.] cannot be ruled out. At such low doses and low dose rates, it must be acknowledged that the lower limit of the range of uncertainty in the risk estimates extends to zero." (Parenthetical statement has been added. (Ref. H.23).

Continuing, the BEIR V Committee also stated:

> "The methodology and values given by ICRP (for calculating the doses due to the internal deposition of radionuclides) were assembled for radiological protection purposes. Thus, the values chosen for the various parameters are conservative; that is, they can lead to overestimates of risk factors. These values may not be appropriate for estimation of risk when the organ and tissue doses received by exposed individuals are considered." (Ref. H.23).

Recently, the NCRP has estimated and published the results of an analysis of the uncertainties in the risk coefficients. The NCRP stated the analyses:

> ". . . show a range (90 percent confidence intervals) of uncertainty values for the lifetime risk for both a population of all ages and an adult worker population from about a factor of 2.5 to 3 below and above the 50th percentile value" (Ref. H.21).

The NCRP went on to say in the same report,

> "This work indicates that given the sources of uncertainties considered here, together with an allowance for unspecified uncertainties, the values of the lifetime risk can range from about one-fourth or so to about twice the nominal values" (Ref. H.21).

This appendix presents estimates of the impacts associated with very small chronic doses to both individuals and the population. The FG believes, based on the information presented above, that these risk estimates presented in this appendix are conservatively high; in fact, the conservatisms and uncertainties are such that the actual level of risks presented in Table H-1 may be zero.

H.7.2 Conservatism in dose estimates for internally deposited radionuclides

The risk coefficients that have been developed by the ICRP are based to a major extent on data generated through the epidemiological studies of the survivors of the World War II atomic bombings in Japan. The people who were exposed received relatively high doses, at high dose rates, and primarily from sources external to the body. In contrast, any exposures to members of the public that may result from material in the ORWBG, will be almost exclusively due to the deposition of radionuclides within the body.

Long-term biological effects of internally deposited radionuclides have not been observed in human population except for the radium dial painters, underground uranium miners exposed to radon, and patients treated with radium and Thorotrast and with relatively large quantities of radioiodine. It is important to note, however, that additional information is being developed through studies of people exposed in the former Soviet Union. (Ref. H.1).

The application of risk coefficients derived from the Japanese studies to assess the effects/risks of radionuclides, localized in as few as one organ or tissue will likely introduce unwanted conservatism. (Ref. H.1). The risk coefficients derived from the Japanese studies are burdened with many uncertainties. These include the application of a common dose and dose rate effectiveness factor (DDREF). It is therefore not clear how these risk coefficients relate to internally deposited radionuclides. Nevertheless, these risk coefficients have been incorporated into risk assessment manuals, including the manual for "Estimating Radiogenic Cancer Risks," published by the U.S. Environmental Protection Agency (Ref. H.7). (Ref. H.1).

The magnitude of the impacts of the uncertainties in the DDREF value illustrate the uncertainties in the fatal cancer risk coefficient estimated to be applicable to a U.S. population of all ages. In Report No. 126 (Ref. H.21), the NCRP estimated that the mean value for this coefficient was 399×10^{-4} per Sv (3.99 per rem). This compares to the value of 500×10^{-4} per Sv (5.0 per rem) estimated by the ICRP (Ref. H.11) for average population groups the world over. The NCRP also estimated that, in the case of the U.S. population, the 90th percent subjective confidence interval (5th to 95th percentile) ranged from 120×10^{-4} per Sv (1.2 per rem) to 884×10^{-4} per Sv (8.89 per rem). They also estimated that about 38 percent of this uncertainty originated in value assumed for the DDREF. This means that the "true" value of the fatal cancer risk coefficient ranges from about 30 percent to about 220 percent of the mean.

It should be noted that most of the long-term dose to hypothetical ORWBG residents results from the ingestion and inhalation of long effective half-life radionuclides (e.g., plutonium 238 and 239). In 1993 the NCRP stated the following:

> "For radionuclides with a long effective half-life in comparison with the remaining years of life of the individual exposed, neither a full expression of the risk nor the total dose would be manifested. For this reason, the committed equivalent dose and the committed effective dose from the life-long intake of radionuclides of very long effective half-life will overestimate by a factor of approximately two, or more (Ref. H.15), the lifetime equivalent dose or effective dose. These quantities, therefore, are not particularly useful for estimating health effects or assessing probability of causation" (Ref. H.18).

Based on the NCRP's position, the lifetime risk calculated for the maximally exposed intruder presented in Table H-1 was reduced by a factor of 2 to represent a more realistic estimate of actual risk. Similarly, because much of the ORWBG resident dose was due to long-effective half life radionuclides, the FG believes that the lifetime risk factors for these hypothetical individuals is overestimated in Table H-1.

H.7.3 Conservatisms based on future research

Radiation hormesis

Although human response to radiation exposure has been extensively studied for more than 75 years, there is still much that is not known about effects of chronic exposure to low-level radiation. This is why, in 1998, EPA and DOE called upon the National Academies of Science - National Research Council (NAS/NRC) to reconvene the Committee on Health Risks from Exposure to Low Levels of Ionizing Radiation (BEIR VII) to analyze the large amount of data published since the last Committee report (Ref. H.23), in 1990. The committee will consider relevant data derived from molecular, cellular, animal, and epidemiologic studies in its comprehensive reassessment of the health risks resulting from exposures to low-level ionizing radiation.

In 1995, the National Academies of Science/National Research Council Committee on Assessment of Center for Disease Control Radiation Studies (Ref. H.24) stated the following:

> "From the beginning of time, humans have lived in a 'sea of radiation,' namely that which results from natural background (cosmic and terrestrial radiation, and naturally occurring radionuclides in our air, water, and food). The accompanying dose rates are estimated (Ref. H.16) to be three times the current dose rate limit for members of the public. If exposures to these sources had led to any significant health effects, humans would never have been successful in reaching their current stage of development."

In the same report, the committee went on to say:

> "Traditionally, radiation protection guidelines are predicated on a linear dose response, which assumes that the harmful effects of radiation are linearly related to the dose and that there is no threshold dose. Most experts believe this assumption is conservative; that is, it overestimates the effects of ionizing radiation at low doses because it ignores the potentially beneficial effects of the body's repair mechanisms [radiation hormesis]."

It is for these reasons that the BEIR VII committee has been charged with assessing the current status and relevance to risk models of biological data and models of carcinogenesis, including critically assessing all data that might affect the shape of the response curve at low doses, in particular, evidence of thresholds or the lack thereof in dose-response relationships and the influence of adaptive responses and radiation hormesis. The outcome of this review may either (1) confirm the linear no-threshold hypothesis; (2) confirm the evidence that there is a threshold below which no harmful effects occur; or (3) perhaps even show that there are beneficial effects in the low dose range. Because of the need to assure that our radiation protection standards are adequate, and that we are not spending money on non-existent problems, the FG believes application of the results of this review be incorporated in decisions regarding the ORWBG.

Medical cure for cancer

Another source of conservatism is that, as cited above, the primary reason for setting a limit on the annual committed dose due to radionuclide releases from the ORWBG, is to avoid the induction of cancer among the people in the hypothetical critical group. As advances are achieved in developing cures for various types of human cancers, the numerical values of the fatal cancer probability coefficients and, in turn, the effective doses derived using the tissue weighting factors, will decrease in magnitude. Similar reductions will occur in the coefficients needed for converting these doses into the associated risks. As pointed out by the NCRP:

> "At some future time, it is possible that a greater proportion of somatic diseases caused by radiation will be treated successfully. If, in fact, an increased proportion of the adverse health effects of radiation prove to be either preventable or curable by advances in medical science, the estimate of the long-term detriments may need to be revised as the consequences (risks) of doses to future populations could be very different." (Ref. H.19).

Unless these advances are taken into account, this could result in a considerable inflation in the conservatisms already existing in the significance of the annual committed dose estimates presented in this report, particularly in the longer-range projections of the risks that the dose estimates doses will impose.

H.7.4 Uncertainties in 10,000 year predictions

This appendix has discussed uncertainties in the models used to calculate health effects of radiation exposure. In addition, estimating risks 10,000 years into the future requires numerous assumptions about human society for which there is no scientific basis. The following discussion was taken from *Technical Bases for Yucca Mountain Standards* (Ref. H.30*)*, a 1995 National Academy of Sciences position paper on the difficulty of predicting risks far into the future. Both EPA (proposed 40 CFR 197) and NRC (in NUREG 1573 [Ref. H.31]) have adopted the NAS' position in evaluating performance assessments at Yucca Mountain.

Reference H.30 makes the following points. It is not possible to predict with any certainty whatsoever societal factors that must be specified in any future scenario. It is impossible to predict human patterns of behavior, societal norms, or technologies even 100 years into the future, much less 10,000. For this reason, a particular scenario generated to assign a potential risk must not be interpreted as something that is likely to happen. It should only be used to provide a reasonable framework for people to use to evaluate protection of human health and the environment. Reference H.30 goes on to conclude, exposure scenarios should be based on best scientific judgment, and not on unreasonable assumptions regarding habits and sensitivities that affect risk. The selection of exposure scenarios is one of the most challenging aspects of risk and compliance assessment. This logic was used by the ORWBG FG in reaching the conclusions contained in this report.

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Appendix I.
Comparative Inventories for DOE Sites

Purpose
This appendix compares the relative inventories of transuranic (TRU), low-level and mixed low-level wastes (LLW and MLLW), tritium and hazardous waste (HW) burial sites in the Department of Energy (DOE) complex. The comparisons also note the methods for environmental remediation of these sites. The DOE Long-Term Stewardship Programs within DOE's Office of Environmental Management (EM) control the closure of the burial sites. These programs incorporate DOE's Environmental Restoration (ER) Program. Many ER sites across the DOE complex have good potential for requiring only caretaker requirements. Remaining ER sites will require closure under various closure and post-closure authorities. The Long-Term Stewardship Plan for the ORWBG is discussed in Section 4 and of this report. Commercial sites are not discussed in this appendix.

The ER Program restores locations where hazardous, radioactive, or mixed waste releases to the environment have occurred or are suspected to have occurred. There are more than 9700 ER sites/waste units in the EM Program, and they occur at national laboratories, research facilities, test or production reactors, and processing areas under various closure authorities (e.g., DOE, NRC, RCRA, CERCLA, Multi-Party/Multi-Agency agreements). By the close of FY00, 46 percent of the ER sites were scheduled to have their remediation/completion phase completed and 44 percent were scheduled to have their site assessments completed. There are 515 ER sites/operable units at SRS. Of the SRS sites 54 percent are in the remediation/completion phase and 46 percent in the assessment phase.

The discussion below is based on a presentation to the ORWBG FG on December 6, 2000, (Ref. I.1) and several other DOE publications noted as references.

I.1 TRU-Contaminated Material

The official, operating definition of TRU-waste as taken from federal legislation is as follows: "Radioactive waste containing more than 100 nanocuries (3700 becquerels) of alpha-emitting transuranic isotopes per gram of waste with half-lives greater than 20 years except for (1) high-level radioactive waste, (2) waste that the Secretary of Energy has determined, with the concurrence of the Administrator of the Environmental Protection Agency, does not need the degree of isolation required by 40 CFR Part 191 disposal regulations; or (3) waste that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61" (Ref. I.2).

To reflect Atomic Energy Commission radioactive waste disposal practices before the 1970s involving TRU-contaminated materials, which is a subject of this report and of the June 2000 report (Ref. I.2), the definition must be expanded to include other isotopes that would not by today's definition qualify as TRU wastes.

In summary Table I-1, below, shows that for in-situ disposal of shallow buried TRU, SRS has buried, by Curies (Ci), about one third the TRU waste that Hanford has buried, about 60 percent of that buried at INEEL, and about the same amount as LANL. Hanford, INEEL and LANL are in arid environments. NTS and ORNL TRU Waste burials are fairly insignificant.

The Waste Isolation Pilot Plant (WIPP) provides for deep burial of TRU-contaminated wastes in bedded-salt deposits in southeastern New Mexico. WIPP is operated as an experimental facility at present; however, it is being evaluated as a permanent deep disposal facility for defense-related TRU waste that requires such disposal.

Table I-1 gives the buried TRU waste (shallow burial at less than 30 meters) for selected DOE sites. The table gives the volume of waste, the TRU curies buried, curies after decay to 2006 and the proposed method of final disposal (Ref. I.2). Additional information can be obtained from References I.1 and I.2.

Table I-1
Buried TRU Wastes

		Curies		
SITE	**VOL (M^3)**	**BURIED**	**w/DECAY at 2006**	**PROPOSED METHOD OF FINAL DISPOSAL**
INEEL	36,800	634,000	297,000	Trenches: 30,000 Ci (2006) in-situ containment: Pits: 267,000 Ci (2006) removal, treatment, shipment to WIPP
Hanford	75,800	67,800	60,000	59,300 Ci (2006) in-situ containment: 720 Ci (2006) Removal with waste treatment
LANL	8,620	21,000	21,000	In-situ containment with engineered cover
SRS – (Total)	4,530	21,900	18,500	In-situ containment
NTS	21	229	152	Not available
ORNL	570	6+	6+	In-situ containment NA 6+ Ci may require removal
TOTAL	126,300	745,000	396,500	128,000 Ci (2006) in-situ containment 267,700 Ci (2006) removal

Table I-2 of this appendix summarizes TRU-waste burial statistics for sites on the SRS.

Table I-2
TRU Buried at SRS

LOCATION	VOLUME BURIED		At 2006 (Curies)
	(M^3)	(Curies)	
ORWBG (643-G)	4,530	18,300	17,100
LLRWDF (643-7G)*	Not available	98	38
MWMF (643-28G)**	Not available	3,540	1,390

* Low Level Radioactive Waste Disposal Facility
** Mixed Waste Management Facility

The June 2000 report (Ref. I.2) states that the most recent risk estimate for buried TRU-contaminated wastes is that prepared for WIPP Final Environmental Impact Statement II (SEIS II) (Ref. I.3). SEIS II contained a "no-action" assessment of health risks associated with leaving in place the buried TRU wastes at Hanford, INEEL, LANL, ORNL, and SRS. The buried waste volumes in Ref. I.2 are generally in good agreement with those in SEIS II, but the radionuclide concentrations and thus the inventories used in the SEIS II analysis were conservative (higher) by factors ranging from .2 (for INEEL) to more than 20 (for SRS). The analysis for buried TRU wastes as performed in SEIS II results in an overestimate of the actual risk. (Ref. I.2)

The SEIS II estimates that a total of 13 latent cancer fatalities may be atttibuted to buried TRU wastes over a period of 10,000 years, largely due to exposures at INEEL and LANL. As the inventories used in SEIS II calculations are conservative, a more realistic estimate is probably less than 10 latent cancer fatalities over 10,000 years (assuming no intrusion into the buried wastes). In comparison to all benchmarks of acceptable risks known to DOE, such risks would be considered very low (Ref. I.2).

As the curies of TRU waste buried at SRS are significantly less than those at Hanford and INEEL and comparable to those at LANL and the overall DOE risk from TRU buried wastes is estimated to be very low, the ORWBG FG concludes that: (1) the risk at the ORWBG is not greater than at other DOE sites with substantial buried TRU wastes and is so low as to be considered negligible (**Conclusion I.1**) and (2) the TRU wastes should remain buried in place (**Conclusion I.2**).

I.2 Radioactive Materials

DOE burial sites with radioactive materials are summarized in Table I.3 below. The types of wastes are shown as low level wastes (LLW) – radioactive only, mixed low level wastes (MLLW) – hazardous and radioactive, and hazardous (HW) – hazardous only. The proposed method of disposal is also shown. Table I.3 is based on Reference I.1.

Table I.3
Buried Radioactive Wastes

SITE	TYPE	METHOD OF FINAL DISPOSAL
Argonne Nat. Lab.	LLW	Composite cap
Brookhaven Nat. Lab.	HW and LLW	Multi-layer caps
Fernald	LLW	Synthetic liner and cap
Hanford	LLW,MLLW and RCRA	Cap; Environmental Restoration Disposal Facility; RCRA closure; Areas adjacent to Columbia River will be relocated
INEEL	LLW	Cap
Livermore Nat. Lab.	MLLW	RCRA closure
NTS	LLW and MLLW	Radioactive Waste Management Site
ORNL	LLW	Cap
Paducah		Closure costs in excess of $7 million in perpetuity
Palos Forest	LLW	Contaminated soils stabilized, isolated and capped
Portsmouth	HW and LLW	Hydrological isolated and multi-layered caps
Sandia Nat. Lab.	Chemical and MLLW	RCRA closure
SRS-ORWBG	MLLW, LLW and HW	Engineered rainwater infiltration controls; stabilize old solvent tanks; RCRA closure When all ground water contamination standards are met at the ORWBG perimeter; active access and land use controls
Weldon Springs	HW and LLW	Synthetic and clay liners; Rock and soil cap
West Valley	HLW LLW and TRU	Removed and vitrified Disposed off-site

The buried inventory at SRS of MLLW represented 8 percent by volume of the MLLW that had been buried at DOE sites through 1977. MLLW burial at INEEL, ORNL, Portsmouth and RFETS exceeded that buried at SRS. The analysis in the recent Programmatic Environmental Impact Statement (PEIS) for waste management (Ref I.4) shows the hypothetical-farm-family to be the most exposed individual with a cancer fatality probability for the DOE sites. The inventory of LLW at SRS represented 16 percent by volume of the LLW that had been buried at other DOE sites prior to 1977. LLW buried at ORNL exceeded that buried at SRS. The hypothetical-farm-family cancer fatality probability, determined in that PEIS, for the LLW disposal are; SRS $4x10^{-6}$, Hanford $4x10^{-5}$, and ORNL $2x10^{-7}$ (Ref. I.4). The ORWBG FG concludes that the ORWBG LLW and MLLW amounts and associated risks are comparable to other DOE sites and should be left in place (**Conclusion I.3)**

I.3 Tritium Contaminated Ground Water

Within the DOE complex, plumes of tritium-contaminated ground water are being managed in various ways. At SRS, the tritium-contaminated ground water is the most significant short term problem for the ORWBG and the analysis presented in Section 5 of this report, Appendix D, and Appendix E shows this tritium presents no significant human health risk.

The various management methods and sites employing them (Ref. I.1) are given in Table I.4.

Table I.4
Tritium Contaminated Groundwater
And DOE Selected Remediation

- **<u>Monitored Natural Attenuation (MNA)</u>**
  Radioactive decay, long-term hydrologic monitoring, restricted land use, positive access controls to groundwater
  - Underground nuclear denotation and test sites (10)
  - Energy Technology Center, CA (levels currently below standards)
  - Laboratory for Energy and Health Related Research, CA
  - LBNL, CA
  - LLNL, CA (Site 300)
  - Burke County Aquifer, GA
  - LANL, NM (Trench Area-50)
  - Mound Plant, OH
  - Oak Ridge, TN (Y-12 S-3 ponds)

- **<u>MNA and Pump-Treat-Reinject</u>**
  - BNL, NY (High Flux Beam Reactor)
  - LLNL, CA (Main site)
  - SRS, SC (F and H Areas seepage basins)

- **<u>MNA and Restricted Access</u>**
  - INEEL, ID (Operable Unit 1-07B)

- **<u>MNA and Phytoremediation</u>**
  - ANL, IL (319 Area)

- **<u>Surfacewater Management with Phytoremediation</u>**
  - SRS, SC (ORWBG southwest plume) **NOTE:** The ORWBG FG does not agree that this is the appropriate remediation method for the ORWBG

- **<u>MNA and Containment</u>**
  Hydrologic isolation (unspecified)
  - ORNL, TN (Trenches, waste area groups 4,5and6)

Table I.4 (Contd.)
Tritium Contaminated Groundwater
And DOE Selected Remediation

- **Monitoring with Decision Pending**
  Access restrictions to groundwater
  - Hanford, WA (9 Production reactors and 200 Area separations facilities)
  - SRS, SC (Production reactors R, L, P and K and NW, NE and SE plumes)

The duration for monitoring with natural attenuation would be until the tritium levels meet the appropriate drinking water standards. The ORWBG FG concludes that MNA with an appropriate mixing zone is a sufficient management method for tritium-contaminated ground water at the ORWBG **(Conclusion I.4)**.

I.4 Hazardous Wastes

Hazardous waste consists of nonradioactive waste materials generated as a result of nuclear weapons production and other research and development activities. HW is any "solid" waste, not otherwise precluded from regulation under the RCRA, that exhibits the characteristics of ignitability, corrosivity, reactivity, or toxicity as defined by RCRA, or which has otherwise been determined to pose a hazard and which has been designated by the RCRA as a listed HW. RCRA defines a "solid" waste to include solid, liquid or contained gas. (Ref. I.4)

The HWs for the ORWBG, as identified in Appendix D, are VOCs, cadmium, mercury and lead. The ORWBG VOC's that have entered the groundwater are primarily trichloroethylene (TCE) and tetrachloroethylene (PCE) (Ref. I.5). Other VOC Constituents of Interest (COI) for the ORWBG are toluene, trimethybenzene, and xylene (Ref. I.6).

Estimated maximum groundwater quality exceedances from hazardous chemicals at various DOE sites (Ref. I.4) are given below:

Hanford	benzene, carbon tetrachloride, 1,2-dichloromethane and methyl chloride
INEEL	none
LANL	methyl chloride
NTS	none
ORNL	1,2-dichloromethane and methyl chloride
SRS	benzene, carbon tetrachloride, 1,2-dichloromethane and methyl chloride

As none of these chemicals are listed as COIs for the ORWBG in the CMS/FS (Ref. I.6) and the HWs listed for SRS are consistent with those for other DOE sites, the ORWBG FG concludes that SRS HW are similar to that at other sites (**Conclusion I.5).**

References for Appendix I

I.1 *"Buried Transuranic- Contaminated Waste Information for U.S. Department of Energy Facilities"*, US Department of Energy, Office of Environmental Management, June 2000. (www.em.doe.gov/integat/buriedtru.html)

I.2 *"Long-Term Stewardship Program Perspectives"*, Rod Rimando, US DOE-SROO, Old Radioactive Waste Burial Ground Public Focus Group Meeting, December 6, 2000.

I.3 *"Waste Isolation Pilot Plant Disposal Phase – Final Supplemental Environmental Impact Statement"*, US Department of Energy, Carlesbad Area Office, Report Number DOE/EIS-0062-S-2, 1997.

I.4 *"Final Waste Management Programmatic Environmental Impact Statement for Managing, Treatment, Storage, and Disposal of Radioactive and Hazardous Waste",*DOE/EIS-02000-F Vol. I, US Department of Energy, Office of Environmental Management, May 1997.

I.5 "*Environmental Assessment for the Interim Measures for the Mixed Waste Management Facility Groundwater at the Burial Ground Complex at the Savannah River Site"*, DOE/EA-1302, US Department of Energy, Savannah River Operations Office, December 1999.

I.6 *"Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-E",* Westinghouse Savannah River Company, Report Number WSRC-RP-98-4012, Rev 0, March 1999.

Appendix J.

History of Interactions Between Stakeholders, SRS and Regulators on ORWBG Remediation

This appendix documents the history of the interactions between stakeholders, regulators and SRS management on the remediation actions associated with the ORWBG. As in any series of discussions between citizens, scientists, owners, and regulators, deliberations and decisions do not follow a straight line. Public support for the decisions made at SRS has ranged from widespread agreement (e.g., the employment of plug-in-rods to reduce regulatory paperwork and closure of the high-level waste tanks) to less than full agreement (e.g., the closure of the Consolidated Incineration Facility).

A similar history has been experienced at the ORWBG. The ORWBG has the potential to be one of the largest remedial actions undertaken at SRS. This potential has led to several actions by stakeholders with limited success.

The first major action on the ORWBG by the Citizens Advisory Board (CAB) occurred on March 26, 1996 (Ref. J.1). It resulted in CAB Recommendation Number 19 (Ref. J.2). This recommendation supported the interim action preferred by the three agencies to place a soil cover over the ORWBG. SRS and SCDHEC accepted the Board's support, and the soil cover was installed. The requested cost benefit analysis, however, was not prepared by SRS.

The second major action by the Board on the ORWBG occurred on November 17, 1998 (Ref. J.3). It formally initiated the focus group (FG) to oversee the closure of the ORWBG. SRS and SCDHEC concurred with this Board recommendation; EPA said that it would participate in the discussions held by the FG but that EPA's decisions would continue to be consistent with CERCLA. The implication of the EPA response was that their flexibility in concurring with the recommendations from the CAB would be limited by EPA's interpretation of the CERCLA rules.

The third major action on the ORWBG by the CAB occurred on January 26, 1999 (Ref. J.4). It initiated a review of the interim corrective measures proposed for the ORWBG SW groundwater plume in the form of an independent scientific peer review (ISPR) conducted by Dr. Joel Massman, University of Washington (Ref. J.5). Dr. Massman recommended that the three agencies justify the interim remedial proposals for the SW plume which ranged up to an estimated $4.725 million for a pump-and-treat system. As a result of the questions raised by the ISPR, the three agencies adopted a more reasonable interim action with an estimated cost of about $500,000. The Board passed CAB Recommendation 75 (Ref. J.6) which supported continued monitoring and other passive actions, but limited support for the other actions proposed for the SW plume unless those actions could be shown to clearly reduce tritium concentrations or provide measurable benefits to human health and the environment. (As of this date neither SRS nor the regulators have produced documentation showing this significant reduction.) The Board also asked to be involved earlier in the decision processes of the three agencies.

Recommendation 75 on the interim remediation of the SW plume was controversial and resulted in a minority report (Ref. J.7) which expressed concern about the existing levels of tritium in downstream river waters (the vote was 10 in favor, 7 against, and 1 abstention; a minority report was signed by all 7 who voted against the recommendation). EPA agreed with the concerns of the minority but also expressed support (Ref. J.8) for continuing to involve stakeholders in the decision making process and with the need to justify the preferred actions chosen by the three agencies.

Regulators had pushed for a wider and more costly array of interim remediation projects at the ORWBG (Ref. J.9); in contrast, the FG had recommended that no remedial action occur without first establishing a demonstrable benefit, primarily to human health (Ref. J.6). This difference in perspective resulted in a compromise RCRA corrective action (Ref. J.10) to impound tritiated groundwater reaching the surface and pump it to native pine trees to phytoremediate the tritium in the groundwater. In comparison to the costly pump-and-treat system operating to remediate the F and H groundwater plume, this system will provide the time for tritium to decay at a reasonable cost.

The fourth major action by the Board on the ORWBG occurred in the spring of 1999 as part of a review of the SRS Corrective Measures Study/Feasibility Study (Ref. J.11). This review resulted in CAB Recommendation Numbers 86 and 98, (Refs. J.12 and J.13). These recommendations were initiated by the FG. CAB Recommendation 89 requested that the three agencies assure that the actions chosen for the final remediation of the ORWBG address benefits versus costs of alternatives, address the 22 old solvent storage tanks, and that monitored natural attenuation be considered as one of the remedial actions. In their responses, EPA and SCDHEC supported the CMS/FS approach, but not of the specific recommendations of the Board. CAB Recommendation 98 recommended a clarification of institutional control, and an integration of the different regulatory rules to present a seamless picture for the solicitation of public input (like the CMS/FS and CERCLA).

About this time the proposed interim actions were finalized. They consists of:

- Installation of a sheet pile dam
- Implementation of an irrigation system for pine trees
- Drainage enhancements near the ORWBG
- Installation of three to four recirculation wells to manage the VOC plume

The FG did not agree with the final interim actions chosen by the three agencies for the ORWBG because they did not demonstrate improved human health from decreased releases and did not show any cost-benefit. The FG wrote a letter to SCDHEC to express its reservations on October 18, 1999 (Ref. J.14). In its letter, the FG opposed the long-term remediation of the SW plume because no evidence had been adduced by either SRS or the regulators to show that the effluents in the SW plume at existing levels of concentration would cause adverse health effects. Although EPA had earlier agreed that remediation must demonstrate a benefit, according to the FG, if existing levels of contamination could not be shown to constitute a health threat, the long-term remediation projects under consideration would not be able to demonstrate a benefit.

The fifth major action by the Board on the ORWBG is not recorded on the Board's web site because it was an internal CAB action. The Board decided at its July 1999 meeting (Ref. J.15) to conduct an ISPR of the final remediation actions proposed for the ORWBG. This decision was widely supported by board members, regulators, and SRS. It resulted in an ISPR conducted by the Education, Research and Development Association (ERDA) of Georgia Universities, chaired by Dr. Ratib Karam. The ERDA ISPR report (appended as Appendix C of this report) was a prospective study of the health effects of current and projected releases from the SW groundwater plume. The report concluded that the current levels of contamination in the SW plume and releases from it were not a threat to human health. The FG prepared a letter (Ref. J.16) documenting these findings and it was read into the CAB meeting record (Ref. J.17). Due to the recent acceptance of the report by the Board, it is too soon to know whether the ISPR report has impacted any of the decisions by the three agencies.

The ERDA ISPR report did solidify the thinking of the FG on the health impacts of the proposed final remediation projects under consideration by the three agencies. At the request of the CAB on July 25, 2000, the FG replied, in its letter of November 6, 2000 to administratively close CAB Recommendation Number 106 (Ref. J.18). It stated that the population dose from the SW plume would remain low and essentially unchanged without remediation. Reference J.16 stated that the interim action would create a new atmospheric exposure pathway for the SRS population by moving 40 percent of the total population exposure from the current down-river water-drinking population to a much smaller population group (relative to the F and H Area seepage basins remediation operations). This new pathway was not evaluated in the NEPA documentation for this interim action.

In summary, the FG/Board has attempted to establish broad principles for the three agencies and stakeholders similar to those proposed in Massman's ISPR report for the A and M area (see recommendation 96 {Ref. J.19}). Dr. Massman had proposed the following:

- Soils and groundwater at an operational unit (OU) should be fully characterized before selecting a treatment.
- Remediation goals for soils and groundwater should be established with public input before the initiation of treatment.
- The effectiveness of remediation treatment projects in the field should be determined with operational data. Treatment projects should be optimized.
- General remediation projects should not be open-ended; instead, the time and cost spent to remediate an operable unit should be agreed to by the three agencies and stakeholders before remediation is begun.

Adding to Dr. Massman's list, the FG believes that remediation should never be undertaken unless the benefits of treatment are clearly established.

References for Appendix J

J.1 Citizens Advisory Board (CAB) Meeting Minutes, March 26, 1996.

J.2 CAB Recommendation 19, *"Interim Action Proposed Plan for the Old Radioactive Waste Burial Ground at the Savannah River Site",* March 26, 1996.

J.3 CAB Meeting Minutes, November 17, 1998.

J.4 CAB Meeting Minutes, January 26, 1999.

J.5 *"Final Report Independent Scientific Peer Review - Selected Subsurface Remediation Activities, Savannah River Site",* by Joel Massmann, November 9, 1999.

J.6 CAB Recommendation 75, *"Interim Corrective Measures Southwest Plume From Old Radioactive Waste Burial Ground",* January 26, 1999.

J.7 Minority Report for CAB Recommendation 75, *"Interim Corrective Measures Southwest Plume From Old Radioactive Waste Burial Ground",* January 26 1999.

J.8 Environmental Protection Agency Response to Savannah River Site Citizens Advisory Board Recommendation Nos. 75, 80, 83, 86, and 87, by John Hankinson - Regional Administrator, March 23, 2000.

J.9 ORWBG Focus Group Meeting Notes, May 5, 1999.

J.10 *"Interim Measures Plan for Mixed Waste Management Facility (MWMF) Groundwater Southwest Plume",* Westinghouse Savannah River Company, Report Number WSRC-RP-98-4222, Rev. 0, December 1998.

J.11 *"Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground, 643-G",* Westinghouse Savannah River Company, Report Number WSRC-RP-98-4012, Rev. 0, March 1999.

J.12 CAB Recommendation 86, *"Corrective Measures Study/Feasibility Study for the Old Radioactive Waste Burial Ground",* May 26, 1999.

J.13 CAB Recommendation 98, *"Corrective Measures Study/Feasibility Study Generic Comments",* September 28, 1999.

J.14 Letter to John Litton, Director, Division of Hazardous and Infectious Waste Management, Bureau of Land and Waste Management, Department of Health and Environmental Control, on the Proposed RCRA permit – Module IIIE for Mixed Waste Management Facility in Savannah River Site Permit, by Karen Patterson and W. Lee Poe, Jr., October 18, 1999.

J.15 CAB Meeting Minutes, July 27, 1999.

J.16 Letter from FG to CAB Environmental Remediation Committee, by Jimmy Mackey and Lee Poe, November 6, 2000.

J.17 CAB Meeting Minutes, November 14, 2000.

J.18 CAB Recommendation 106, *"Resource Conservation and Recovery Act (RCRA) Permit Modification for the Mixed Waste Management Facility at SRS",* November 16, 1999.

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